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HIGH-VOLTAGE ENGINEERING.*

BY

F. W. PEEK, JR.,

Consulting Engineer, General Electric Company.

THE DIELECTRIC CIRCUIT.

IT is our work as engineers to devise means of transmitting energy electrically from one point to another point, and of controlling, distributing, and utilizing this energy as useful work. In general, conductors and insulating materials are necessary. Transmission problems are principally problems of high voltage and therefore of dielectrics. The dielectric circuit will be briefly reviewed before some of the problems of high-voltage engineering are taken up. In order that energy may flow along a conductor, energy must be stored in the space surrounding the conductor. In this surrounding space there is a magnetic field which is proportional to the current, and a dielectric field which is proportional to voltage. Energy does not flow unless these fields exist together. If the dielectric field exists alone it is often spoken of as static.

Considering the two parallel wires of a transmission line, the magnetic field is represented by closed circles surrounding the

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conductors, the dielectric field by arcs of circles starting on one conductor and ending on the other conductor. These lines of force represent graphically the direction and strength of the field (see Fig. 1).

The energy stored in the dielectric field is

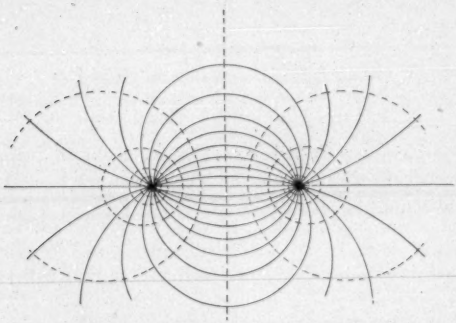
$$\frac{e^2C}{2}$$

and the energy stored in the magnetic field is

$$\frac{i^2L}{2}$$

The energy stored in the dielectric circuit is thus greater for high voltage, and in the magnetic circuit for high currents. It is

FIG. 1.



the see-saw of this energy from one form to another that causes all high-frequency troubles, surges, etc.

When energy was first transmitted, low voltages and high currents were used. The magnetic circuit and magnetic field in this way became known to engineers, and as little trouble was had with insulation, the dielectric field was therefore not generally understood. If insulation broke down, its thickness was increased without regard to the dielectric circuit.

A magnetic circuit would not be built in which the magnetic lines were overcrowded in one place and undercrowded in another place,—in other words, badly out of balance. In these days

of high voltages, it is of even more importance to properly proportion the dielectric circuit. Although an unbalanced magnetic field may mean energy loss, an unbalanced or too highly saturated dielectric field will mean broken-down insulation.

The dielectric and magnetic fields may be treated in a very similar way. For instance, to establish a magnetic field a *magnetomotive force* is necessary; to establish a dielectric field an *electromotive force* or voltage is necessary. If in a magnetic circuit the same flux passes through varying cross sections, the magnetomotive force will not divide up equally between equal lengths of the circuit. Where the lines are crowded together the magnetomotive force per unit length of magnetic circuit will be larger than where the lines are not crowded together. The magnetomotive force per unit length of magnetic circuit is called magnetizing force. Likewise for the dielectric circuit where the dielectric flux density is high a greater part of the electromotive force per unit length of circuit is required than at parts where the flux density is low. Electromotive force or voltage per unit length of dielectric circuit is called electrifying force, or voltage gradient. If iron or material of high permeability is placed in a magnetic circuit the flux is increased for a given magnetomotive force. If there is an air gap in the circuit the magnetizing force is much greater in the air than in the iron. If a material of high specific capacity or permittivity, as glass, is placed in the dielectric circuit, the dielectric flux is increased. If there is a gap of low permittivity, as air, in the circuit, the gradient is much greater in the air than in the glass.

A given insulation breaks down at any point when the dielectric flux density at that point exceeds a given value. It is thus important to have uniform density. The flux depends upon the voltage, the permittivity, or specific capacity of the insulation and the spacing and shape of the terminal. That is,

$$\Psi = Ce$$

The flux density at any point is proportional to the gradient or volts per cm. at that point, and to the permittivity of the dielectric. Thus

$$D = \frac{de}{dx} Kk = gKk \qquad (1)$$

also

$$D = \frac{\Psi}{A}$$

As the density is proportional to the gradient, insulations will therefore also rupture when the gradient exceeds a given value; hence if the gradient is measured at the point of rupture it is a measure of the strength of the insulation. The strength of insulation is generally expressed in terms of the gradient rather than flux density.

The gradient may be thought of as a force or stress, and the flux density as a resulting electrical strain or displacement. Permittivity, then, is a measure of the electrical elasticity of the material. Energy is stored in the dielectric with increasing force or voltage and given back with decreasing voltage. Rupture occurs when the force or gradient exceeds the elastic limit. Of course, this must not be thought of as a mechanical displacement. In fact, the actual mechanism of displacement is not known.

When two insulators of different permittivities are placed in series with the same flux passing through them, the one with the lower permittivity or less electrical elasticity must take up most of the voltage,—that is, the "elastic" one may be thought of as "stretching" electrically and putting the stress on the electrically stiff one.

For instance, take two metal plates in air as in Fig. 2 and apply potential between them until the flux density is almost sufficient to cause rupture. Now place a thick sheet of glass between the plates; the capacity and therefore the total flux is increased. This increases the stress on the air, which breaks down or glows. The glass does not break down. Thus by the addition of insulation the air has actually been broken down. This takes place daily in practice in bushing, etc., and the glow is called static.

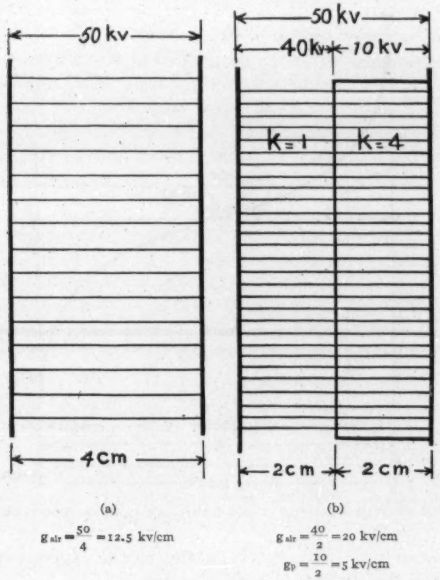
It is especially important in designing leads and insulators immersed in air to avoid overstress on the air.

It can be seen that specifying volts and thickness does not tell the stress on the insulation. The stress on insulation does not depend altogether upon the voltage, but also upon the shape of the electrodes; as, for instance, for needle points—the flux density at the point must be very great at fairly low voltages, while for large spheres a very high voltage is required to produce high flux density. For this reason 200 kilovolts will jump 50 cm. between needle points, while it will only jump about 17 cm. between 12.5 cm. spheres. From the above it can be seen that it is much more important to design the dielectric cir-

cuit for proper flux distribution than the magnetic circuit. Local overflux density in the magnetic circuit may cause losses, but local overflux density in the dielectric circuit may cause rupture of the insulation.

Consider now the two conductors of a transmission line with voltage between them. The dielectric flux begins on one

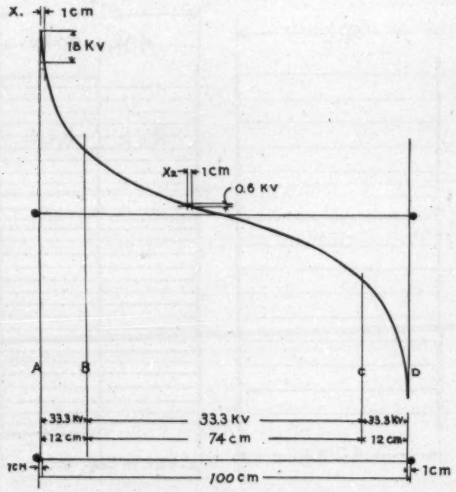
FIG. 2.



conductor and ends on the other conductor (see Fig 1). The flux is very dense at the conductor surface and less so at a distance from the conductor. Hence the voltage gradient is greater at the surface, and breakdown must first occur there. For the particular case shown in Fig. 3 one-third of the voltage is taken up by the space 12 cm. from each conductor, although the total space is 100 cm. The gradient is greatest at the wire surface. That is,

if across a small distance, X_1, the voltage is measured near the wire surface and then again across the same space X_2 some distance from the wire, it is found that the voltage is much higher across the small space X_1 near the wire surface than across the one further out (Fig. 3). In actually measuring the gradient, or rather calculating it, X is taken very small or dx. The voltage

FIG. 3.



Distribution of potential in space between wires of a transmission line.

across dx is de. The purely mathematical expression for the gradient at the surface of parallel wires is:

$$g = \frac{de}{dx} = \frac{e}{2r \log_e \frac{s}{r}}$$

If the conductors are close together a spark jumps across when the voltage is high enough to produce overflux density at the conductor surface; or corona and spark-over are simultaneous. If far apart, corona forms around the conductor surface and spark-

over only takes place at some higher voltage. The condition for spark-over or corona is as follows: Corona is conducting. When it forms it, in effect, increases the size of the conductor. If this increase of conductor size lowers the flux density, the breakdown remains local. If the increase of conductor size increases the flux density or stress, the breakdown must extend across or spark-over takes place. If $\frac{s}{r}$ is large, corona forms out to a point where the flux density is below the breakdown density and stops. If $\frac{s}{r}$ is small, below a critical value, a spark jumps because the corona starts at breakdown flux density and continues on across, as it never reaches a value lower than the breakdown value. The surface gradient at spark-over may, therefore, also be used to measure dielectric strength if the conductors are close enough together so that corona cannot form, or rather spark-over and corona are simultaneous.

INSULATION.

As voltages or electromotive forces become higher the proper shaping and spacing of the conductors to prevent dielectric flux concentration becomes of more importance. Three general types of insulation are used,—gaseous, liquid, and solid. The gaseous insulation, air, is the most universal insulation. It is often part of the insulation when not generally realized. For instance, in the line insulator the air is as much a part of the insulator as the porcelain, as the dielectric flux passes through both, and it is important to so proportion the porcelain part that the air is not overstressed. Transformer oil is the most common liquid insulation. The most common solid insulations are treated and varnished paper and cloth, natural and synthetic gums and resins, mica, oiled linen, pressboard, porcelain, glass, rubber, wood, etc. The mechanism of breakdown of the most common insulations of the different types will be considered.

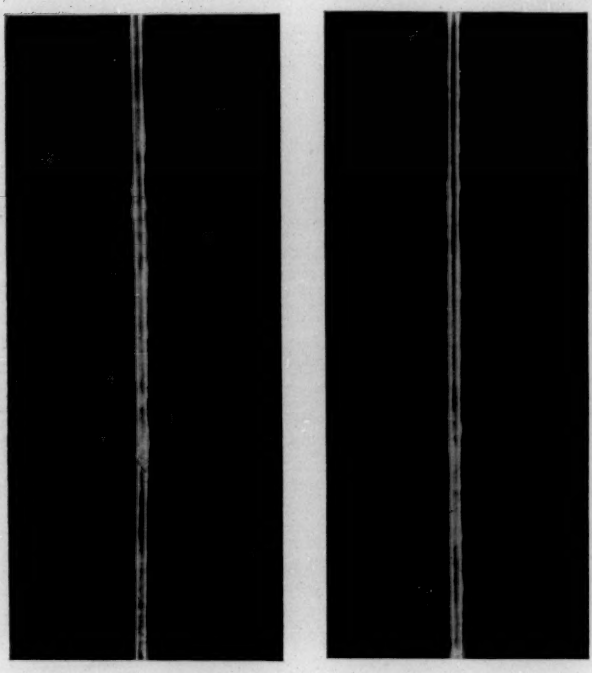
Gaseous Insulation—Air.

Air is the principal insulation of transmission lines; the so-called line insulators are used for mechanical support. When the voltages were below about 60,000 the conductors used had sufficient radius or circumference so that the surface flux density or gradient was not sufficient to cause breakdown. As voltages became higher the sizes of conductors remained about the same, and, therefore, the flux density or gradient became greater. The

air broke down, causing the so-called corona and loss. This led to extensive investigation.

When potential is applied between the two conductors of a transmission line and gradually increased, the first evidence of

FIG. 4.

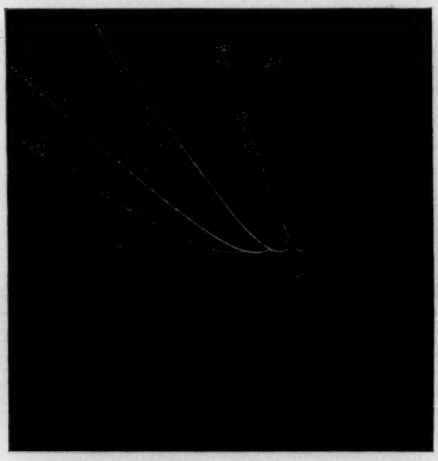


Corona on parallel polished wires.

stress is, if it is dark, glow or brushes at local points where dirt may be on the wire. Wattmeters in the circuit begin to indicate loss. As the potential is increased the whole line very suddenly begins to glow. There is a hissing noise. This point is the visual critical corona point. It is quite definite and decided (see Fig. 4).

The breakdown is extremely sudden. An odor of ozone is noticed near the conductors. The inert oxygen of the air, $O_2(O=O)$, is torn apart as active or atomic O. It recombines as O_2 and O_3 $\left(\begin{smallmatrix} O \\ O-O \end{smallmatrix}\right)$ or ozone. If there is organic matter near, it becomes oxidized. The metal also becomes oxidized. At higher voltages the nitrogen of the air combines with the oxygen. Wattmeters

FIG. 5.



Corona on line.
No. 3/0 cable. 310 cm. spacing—230,000 volts.

in the circuit show that the loss now increases very rapidly with increasing voltage.

The surface flux density or the gradient at which visual corona starts or breakdown occurs is higher for small conductors than large ones,—that is, air around small conductors has an *apparently* greater strength than around large conductors (see Fig. 6). If the potential between parallel wires is increased to the value where corona just starts, and this voltage is found to be

e_v, the surface gradient or gradient at point of rupture is a measure of the apparent strength of air. This gradient is:

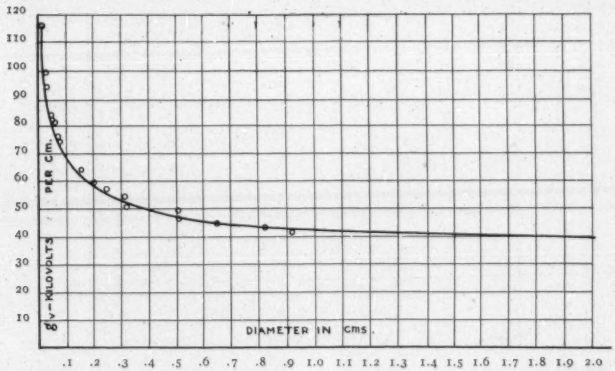
$$g_v = \frac{e_v}{r \log_e \frac{s}{r}} \qquad (1)$$

The approximate gradient at any point X cm. from the centre of the conductor is:

$$g = \frac{e_v}{X \log_e \frac{s}{r}} \qquad (2)$$

where s is the distance between centres in cm. and r is the conductor radius in cm. e_v is kilovolts to neutral. The a–c wave

FIG. 6.



Visual critical voltage gradient (max.). Two parallel wires.

shape must always be known, as it is the maximum value of the wave upon which break-down depends.

We have found by measuring g_v for different sizes[1] of wire that the following law holds:

$$g_v = g_o \left(1 + \frac{0.301}{\sqrt{r}}\right) \qquad (3)$$

[1] "Law of Corona and Dielectric Strength of Air," I, II, III (F. W. Peek, Jr.), *A.I.E.E.*, June 1911, 1912, 1913.

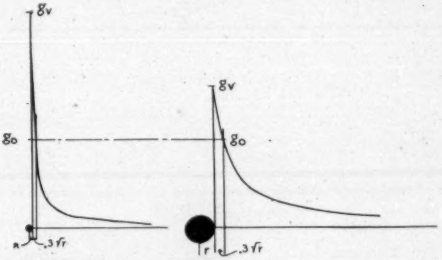
Equating (1) and (3),

$$g_o\left(1+\frac{0.301}{\sqrt{r}}\right)=\frac{e_v}{r\log_e\frac{s}{r}}$$

$$g_o=\frac{e_v}{(r+.301\sqrt{r})\log_e\frac{s}{r}}=\text{constant}=30\,\frac{\text{kv.}}{\text{cm.}}$$

Thus $(r+.301\sqrt{r})=X$ in (2) or g_o is the gradient $.301\sqrt{r}$ cm. from the surface of the conductor at breakdown. This means that at breakdown the gradient is always constant and equal to $g_o=30$ kv./cm. (max.) at $.301\sqrt{r}$ cm. from the conductor sur-

FIG. 7.



g_o is constant at distance $.3\sqrt{r}$ cm. from surface of wire.

face, independent of the size of the conductor, and is shown graphically in Fig. 7 for both a small and large wire. The explanation seems to be that the strength of air is constant and equal to 30 kv./cm., but that energy is necessary to start rupture, and, therefore, rupture cannot start at the surface, but only after the surface gradient has been increased to g_v, in order to store the rupturing energy between the conductor surface and $.301\sqrt{r}$ cm. away in air, where the gradient is g_o. g_v is thus the apparent strength.

Theoretically, g_o should vary directly with the air density, or

$$g_o^1=\delta g_o$$

If the energy theory is true, the energy storage distance should also vary with δ. It has been found that

$$\text{Energy storage distance} = .301\sqrt{\frac{r}{\delta}}^{2}$$

δ is the relative air density. $\delta = \dfrac{3.92b}{273 + t}$

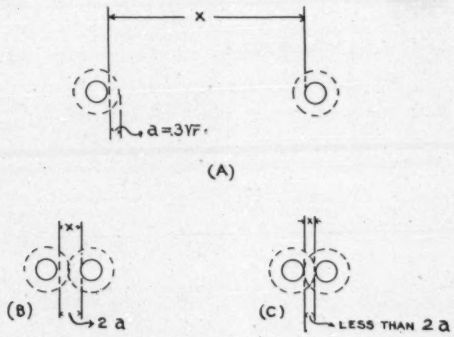
where t = temperature in degrees C., and b = barometric pressure in cm. of mercury. $\delta = 1$ at 25° C. and 76 cm. barometer.

Therefore g_v does not vary directly with δ, but

$$g_v = g_o\delta\left(1 + \frac{.301}{\sqrt{\delta r}}\right)\frac{\text{kv.}}{\text{cm.}}\text{ max.} \qquad (4)$$

The effect is the same whether δ is varied by change in temperature

FIG. 8.



or pressure (over range where there is still no chemical change due to temperature).

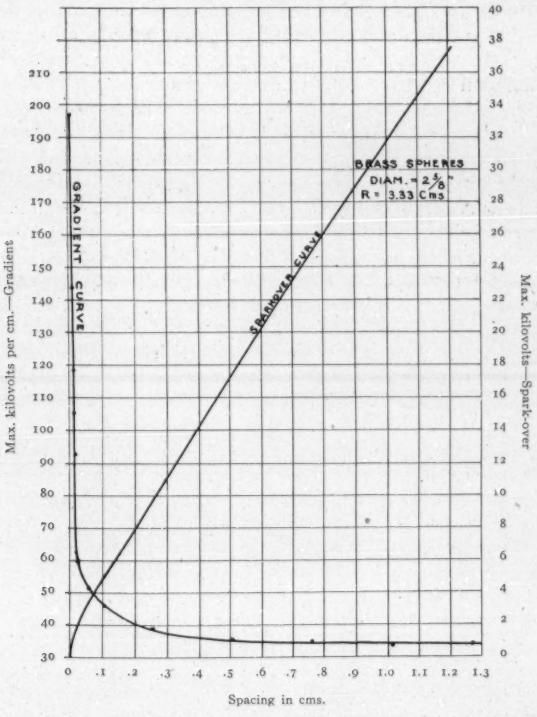
According to the above theory, g_v is independent of the spacing. If, however, the wires are spaced very close together, so as to interfere with the free energy storage distance,—that is, in the order of $.301\sqrt{r}$ cm. (Fig. 8),—g_v should increase so that sufficient energy to start rupture may be stored in the limited distance. This is actually the case, and, for small spacing, very high

[2] "Law of Corona," II, III (F. W. Peek, Jr.), *A.I.E.E.*, June 1912, 1913.

g_0 values have been reached. Fig. 9 shows this effect on 3.33 cm. spheres.

The electron theory may also be very well applied in agreement with the above. Briefly:

FIG. 9.



When low potential is applied between two conductors any free ions are set in motion. As the potential, and, therefore, the field intensity or gradient, is increased the velocity of the ions increases. At a gradient of $g_0 = 30$ kv./cm. ($\delta = 1$) the velocity

of the ions becomes sufficiently great over the mean free path to form other ions by collision. This gradient is constant and is called dielectric strength of air. When ionic saturation is reached at any point the air becomes conducting and glows, or there is corona or spark.

Applying this to parallel wires, when a gradient g_v is reached at the wire surface any free ions are accelerated and produce other ions by collision with molecules, which are in turn accelerated. The ionic density is thus gradually increased by successive collision until at $0.301\sqrt{r}$ cm. from the wire surface, where $g_o = 30$, ionic saturation is reached, or corona starts. The distance $0.301\sqrt{r}$ cm. is, of course, many times greater than the mean free path of the ion, and many collisions must take place in this distance. Thus for the wire corona cannot form when the gradient of g_o is reached at the surface, as at any distance from the surface the gradient is less than g_o.

The gradient at the surface must therefore be increased to g_v so that the gradient a finite distance away from the surface ($0.301\sqrt{r}$ cm.) is g_o. That is to say, energy is necessary to start corona, as explained above. g_o, the strength of air, should vary with δ; g_v, however, cannot vary directly with δ, because, with the greater mean free path of the ion at lower air densities, a greater "accelerating" or energy distance is necessary. In the equation $a = 0.301\sqrt{r}/\delta$; that is, a increases with decreasing δ.

When the conductors are placed so close together that the free accelerating or energy storage distance is interfered with, the gradient g_v must be increased in order that ionic saturation may be reached in this limited distance.

Tests made over a fairly wide frequency range show little effect of frequency on the starting point of corona on wires, or spark-over on spheres, if highly polished. For needle points, rough surfaces, etc., local corona starts at low voltages at any frequency. At low frequency the loss in the brush is very low and the starting point not much affected. At very high frequency the local loss may be so great that hot needle-like streamers extend out, weakening the air in their path. The needle gap spark-over voltage for continuous high frequency is thus made much lower than the 60-cycle spark-over. The sphere is affected to much less extent.

In high-frequency conductors care should, therefore, be taken

to polish the surface, as any little point will start a "spark needle." which may then play anywhere over the surface or cause spark-over at very low voltage.

The voltage at which visual corona starts between polished parallel wires may be accurately calculated from the following formula:

$$e_v = g_v r \log_e \frac{s}{r} \text{ kilovolts to neutral}^3$$

where

$$g_v = 30\,\delta\left(1 + \frac{.301}{\sqrt{\delta r}}\right) \frac{\text{kv.}}{\text{cm.}} \text{ (max.)}$$

$$g_v = 21.2\,\delta\left(1 + \frac{.301}{\sqrt{\delta r}}\right) \frac{\text{kv.}}{\text{cm.}} \text{ (effective (sine wave))}$$

The appearance of corona is different on the positive and negative wires. Fig. 10 shows *a–c* corona on positive and negative parts of the wave.

It becomes of great importance in the design of high-voltage transmission lines to know the various factors which affect corona formation and loss. Loss begins at some critical voltage, which depends upon the size and spacing of line conductors, altitude, etc. For practical transmission lines and frequency near 60 ∞ the corona loss can be expressed by the equation:

$$p = a f (e - e_o)^2 \times 10^{-5} \quad ^4 \qquad (5)$$

where

p = loss in kilowatts per kilometre of single line conductor.

e = effective value of the voltage between line conductors and neutral in kilovolts.

f = frequency.

$$a = \frac{344}{\delta}\sqrt{\frac{r}{s}}$$

r = radius of conductors in cm.

s = spacing between conductors.

δ = air density factor.

e_o = effective *disruptive* critical voltage to neutral in kilovolts.

$$e_o = m_o g_o \delta r \log_e \frac{s}{r} \text{ kv. to neutral.}^3$$

---

[3] Kilovolts between lines divided by 2 for single-phase and $\sqrt{3}$ for three-phase. In terms of maximum, or effective sine wave depending upon value of g_v used.

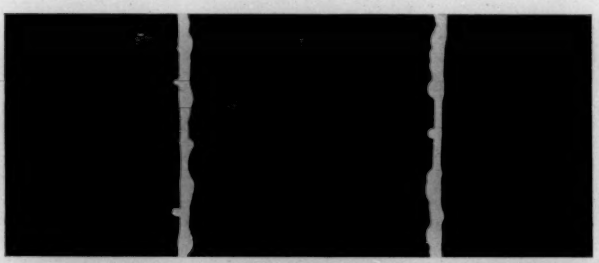
[4] "Law of Corona," I (F. W. Peek, Jr.), *A.I.E.E.*, June, 1911.
Developed by the author, 1910. Discussion, *A.I.E.E.*, Jan., 1911.

g_o is the disruptive gradient of air; for all practical sizes of conductor it is constant and is 21.2 kv./cm. (eff.) [wave is assumed close to sine in these formulæ].

m_o is a constant dependent upon the surface condition.
$m_o = 1$ for polished wires.
$m_o = 0.98$ to 0.93 for roughened or weathered wires.
$m_o = 0.87$ to 0.83 for cables.

FIG. 10a.

No. 13 B. & S. wire. Spacing 12.7 cm. Volts 82,000



(1) Without stroboscope

Left (+) (2) With stroboscope Right (—)

Corona on parallel wires not polished

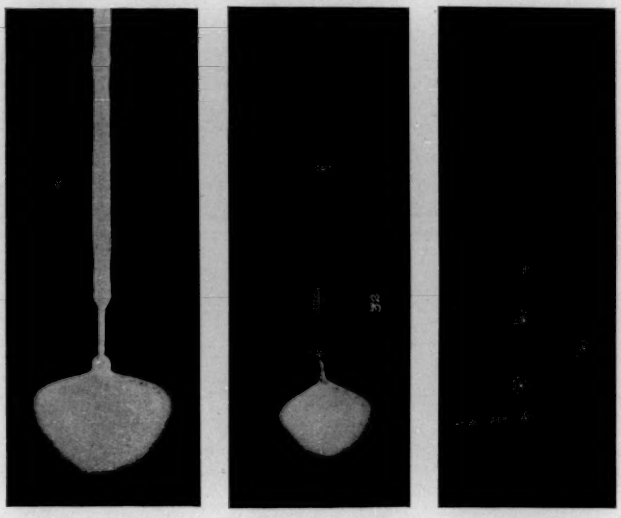
Visual corona does not begin at the disruptive critical voltage e_o, but always at a higher voltage e_v. While, theoretically, no loss of power should occur below e_v, some loss does occur, due to brush

discharge at irregularities of the wire surface, dirt, etc. Practically, however, due to dirt and irregularities the loss starts at e_o and follows the quadratic law given above even between e_v and e_o with sufficient accuracy for practical work. It is interesting to note that the loss below e_v due to chance brushes, dirt, etc., actually follows the probability curve:

$$p_1 = qe^{-h(e_o - e)^2}$$

but this need not be considered in practice, as the loss below e_v is unstable because it depends upon varying irregularities. The

FIG. 10b.



Without stroboscope ∗ With stroboscope + With stroboscope—

One of two parallel polished steel rods pointed at ends. Diameter 0.325 cm. Spacing 10 cm. Volts 180,000.

storm loss really fixes the maximum operating voltage below e_o.

Equation (5) more than covers the practical transmission range of conductor diameter and spacing, etc. A more com-

plete equation for use at lower frequency and also for very small conductors or over greater range in any way is:

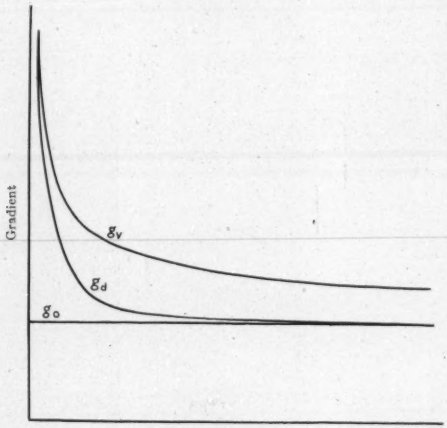
$$p = 241\,(f+25)\sqrt{\frac{r+\frac{6}{s}+.04}{s}}\,(e-e_d)^2\,10^{-5} \qquad (5a)$$

$$e_d = g_d\, r \log_e \frac{s}{r} \qquad \text{(See Fig. 11.)}$$

$$g_d = g_o\left(1+\frac{.3}{\sqrt{r}}\,\frac{1}{1+230\,r^2}\right)$$

Where r is large (above 0.2 cm.) practically $g_d = g_o$, and where r is zero $g_d = g_r$.

FIG. 11.

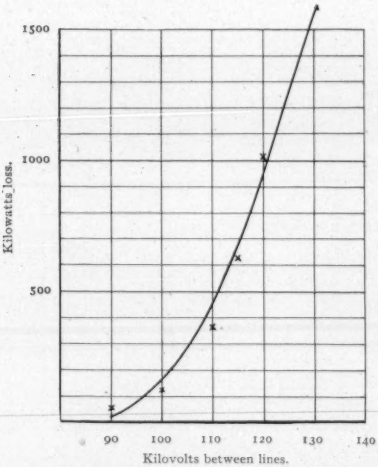


For practical frequencies around 60 cycles, and practical sizes of conductor, (5a) thus reduces to the simple equation (5).

Rain and snow lower e_o and increase the loss. The storm loss can be approximated by taking e_o in (5) at 80 per cent. of the fair weather e_o.

As stated above it is generally not advisable to operate above the fair weather e_0 voltage, as the storm loss then becomes excessive. Fig. 12 shows agreement of measured and calculated loss on practical lines. The calculation is made from formula (5). Fig. 13 shows comparison of fair weather and storm loss.

FIG. 12.



Comparison of calculated and measured losses. *x*, Measured values. Drawn curve calculated from author's corona formula (5). Diameter wire, 0.375 inch (No. 0 cable). Spacing, 124 inches. Three-phase. Line length, 63.5 miles. Barometer, 23.8 inches. Temperature, 51° F. This test for corona was made on Shoshone-Leadville transmission line by Mr. G. Faccioli. Test made on operating line three-phase and at high altitude. The check is interesting because of the number of variables taken into account.

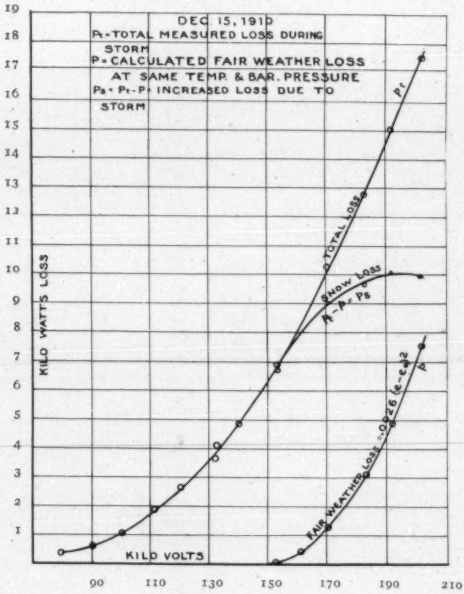
Oil.

In pure oil, as in air, there is no appreciable loss until local rupture, as brush discharge or corona, occurs. The occurrence of brush or corona is extremely sudden. Oil is, therefore, a very desirable insulation, as it can be operated fairly close to its breakdown voltage without heating and consequent lowering of the breakdown voltage.

The mechanism of breakdown in the liquid oil is very similar to that in the gas air. If two very small parallel wires are placed

in clear oil and the voltage is increased, a point is finally reached when glow appears just as corona in air. It appears to extend farther out than the corona in air, and is much less regular. It is much more difficult to detect the starting point than in air, and unless the conductors are very small or far apart (s/r large)

FIG. 13.



corona cannot be seen before spark-over. The strength of oil has been measured on spheres of different sizes, and also on wires in the centre of a cylinder. As for air, the *apparent* strength of oil is greater around small conductors than large ones. For spheres and wires the apparent strength takes the form

$$g_v = g_o \left(1 - \frac{a}{\sqrt{R}}\right)$$

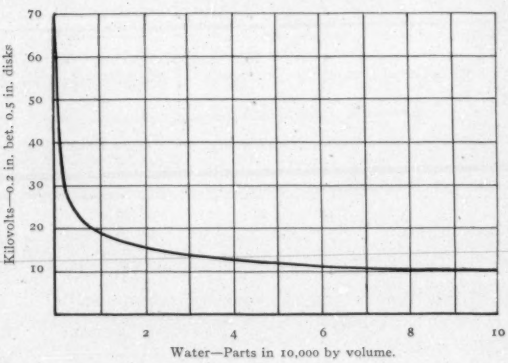
The rupturing energy is much greater for oil than for air. The energy distance is, therefore, also greater—from four to ten times.

The absence of corona, or, rather, the simultaneous appearance of corona and spark-over, unless the wires are very small or far apart, seems to confirm the theory of large rupturing energy distance. Thus, as the voltages increase, corona rupture occurs out to the energy distance; this in effect increases r to such an extent that

$$\frac{s}{r + \text{energy distance}} = \frac{s}{r_1}$$

is less than the ratio at which corona can form.

FIG. 14.



At small spacings, less than the energy distance, the *apparent* strength of oil is also increased. For instance, for 6.7 cm. spheres the breakdown gradient is $g_v = 100$ kv./cm.(eff.). At spacings less than the energy distance values as high as 700 kv./cm. have been reached. When oil is used as an insulation the apparent strength is greatly increased by barriers of pressboard, etc.—first, by limiting the energy distance; second, by preventing dirt particles from lining up.

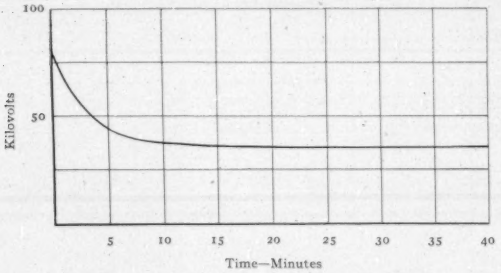
The smallest amount of water greatly decreases the strength of oil (see Fig. 14). Water is, also, always attracted to points of

maximum flux density in order to increase the stored energy. Thus the most highly stressed part is weakened. It is extremely important to remove all moisture from oil in electrical apparatus. This is fairly simple with the filter press oil dryer.

Solid Insulation.

In air and oil (at moderate frequency) a gradient not greatly under the breakdown gradient may be applied and held, and the loss is so small that no appreciable heating results. The loss in air and oil is thus essentially a phenomenon above the elastic limit. This loss generally exists in some locally broken-down part of the insulation, as corona on the surface of a wire.

FIG. 15.



Time test—0.04-inch oiled pressboard (Hendricks).

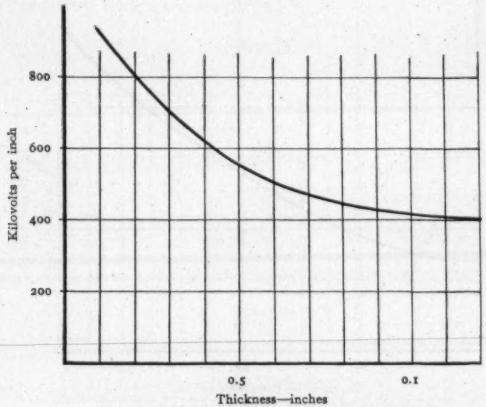
The break does not extend through the whole insulation, and when the stress is removed new air or oil takes the place of the broken-down insulation.

Almost all insulations are partially conducting or have a high resistance, which is spoken of as "insulation resistance." This apparently has no direct connection with the dielectric strength, which is measured by the gradient or flux density required to *electrically* strain the dielectric above the *electrical* "elastic limit." For instance, in a condenser made of two metal plates with a solid dielectric between them, when *a–c* potential is applied energy is stored in the dielectric by electrical displacement at increasing potential and delivered back to the circuit at decreasing potential, so long as the potential does stress the insulation beyond the elastic limit. If the dielectric were perfect a wattmeter in the circuit

would indicate no loss. In all practical solid insulations there is an I^2R loss and a dielectric loss, sometimes called dielectric hysteresis. This loss takes place in solids below the elastic limit.

In solid dielectrics a stress may be applied below the elastic limit and after a short time, on account of heating, and hence weakening, rupture will occur. In all solid insulations the time of application must, therefore, be known. The "instantaneous" breakdown voltage is generally four or five times the voltage at which the insulation will operate indefinitely.

FIG. 16.



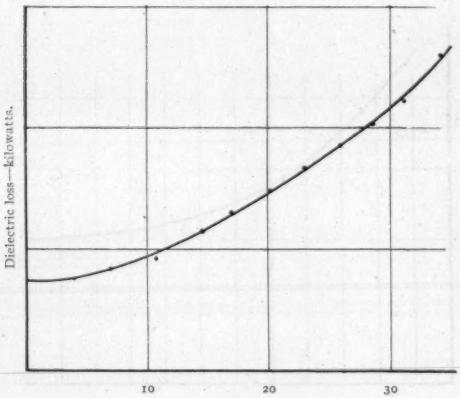
Variation of apparent dielectric strength with thickness—4.0-inch disks (Hendricks).

In making comparative tests on solid insulations it is generally convenient to make some arbitrary time tests which include the effect of dielectric loss, and thus heating, on the breakdown voltage. The effect of loss is cumulative. The insulation becomes warm and the loss increases with the temperature. The dielectric strength generally decreases with increasing temperature. The ultimate strength depends, naturally, upon the rate at which heat is radiated or conducted away. As an example, for a certain insulation and given terminals, if the voltage is applied "instantaneously,"—that is, increased at fairly rapid

rate before heating occurs,—80 kv. is required to cause rupture. If 50 kv. is applied, rupture occurs in four minutes. Thirty kilovolts may be applied indefinitely (under the fixed conditions of test) (see Fig. 15).

One of the arbitrary practical tests for comparing insulation is the one-minute time test. In this test the "instantaneous" breakdown voltage is found. Seventy-five per cent. of this voltage is applied for one minute; if breakdown does not occur the

FIG. 17.



Dielectric loss in a 3750 kva.–120 kv. transformer at 60 cycles (Lewis).

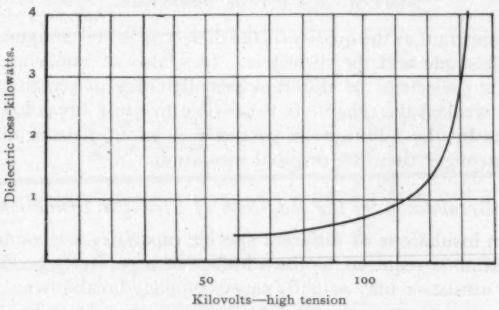
voltage is increased 5 per cent., and one minute allowed to elapse; this is repeated until breakdown occurs. Insulation tests are generally made for convenience between flat terminals in oil.

For a given insulation the puncture voltage per unit thickness $\left(\frac{e}{x}\right)$ is always greater for thin sheets than for thick ones (see Fig. 16). This is due partly to better heat distribution in the thin sheets, partly due to the fact that energy is necessary for disruption and that the energy distance is limited in the thin sheets, and partly due to flux concentration at the edge of the plates. With flat plates the apparent strength of insulation decreases with increasing area approximately along the probability curve.

Laminated insulation is much better than solid insulation, as weak spots cannot line up in laminated insulation, and it is more uniform. The energy distances are also probably limited by the laminations, and, to some extent, the apparent strength is increased in this way.

It requires energy and, therefore, time to rupture insulations; for a given potential a given number of cycles at high frequency are, therefore, much less injurious than the same number of cycles of low frequency. This also applies to impulse voltages of steep wave front. High frequency is, however, generally very injurious for two very distinct reasons:

FIG. 18.



Dielectric loss in a 100 kva.–200 kv. transformer at 60 cycles 200 kv.

(1) On account of the very great energy loss at continuous high frequency the insulation may be literally burned up in a very short time, even at low voltages. This condition does not result in practice from surges, etc., on low-frequency lines.

(2) In certain apparatus containing inductance and capacity local very high potential difference may be caused by resonance, and these may cause rupture simply by overpotential.

As energy is required for rupture of insulation, voltages many times in excess of the rupturing voltage may be applied without rupture if the application is very short. Such voltages are generally called impulse voltages of steep wave front. Each impulse, however, permanently damages the insulation, and if a sufficient number are applied rupture occurs.

The energy loss in insulation at constant temperature varies approximately as the square of the voltage. It increases with increasing frequency and temperature (see Figs. 17 and 18).

For air and for oil there is no appreciable loss except at rupture. This may occur as corona, and when the overpotential is removed fresh insulation takes the place of the broken-down insulation—it is self-healing. With solid insulation there is a loss below the rupturing voltage. If local rupture occurs it generally burns the insulation in such a way that the gradient is increased by charring and complete breakdown results. In the case of glass or porcelain a local breakdown generally causes a local mechanical crack which extends across.

SOME HIGH-VOLTAGE PROBLEMS.

As important as the quality of the dielectric is the configuration of the electrode and the dielectric. It is also of importance in combining dielectrics of different permittivities to see that one does not weaken the other. It is possible to cause breakdown in apparatus by the addition of perfectly good insulation, dielectrically stronger than the original insulation.

Causing Breakdown by the Addition of Stronger Insulation.

When insulations of different specific capacities are combined great caution is required, as the addition of a perfectly good and stronger insulation may actually cause complete breakdown. For example, two spheres were set 2 cm. apart in air. At 40 kv. there was no evidence of stress. A 0.2 cm. thick piece of pressboard with a breakdown voltage of 35 kv. (much stronger than air) was then placed between the spheres, making a total insulation of 1.8 cm. of air (38 kv. breakdown voltage) and 0.2 cm. of pressboard (35 kv. breakdown voltage). Complete breakdown of air and pressboard took place immediately, although the voltage was not increased above 40 kv. The direct sum of breakdown voltages is $38 + 35 = 73$ kv. (see Fig. 19).

The mechanism of breakdown was as follows: When the pressboard was added, on account of its high permittivity, the flux density was increased to a sufficient extent to cause the air to rupture. This put full voltage (40 kv.) on the pressboard, which in turn ruptured.

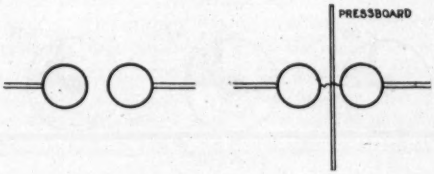
Combining Insulations.

Assume three insulations are available, all of exactly the same dielectric strength, but of permittivity as follows:

Insulation A	$k = 5.4$
Insulation B	$k = 3.6$
Insulation C	$k = 2.0$
Rupturing gradient	$g = 100$ kv./cm.

As a simple example assume it is desired to insulate a 1.0 cm. wire using 1.75 cm. of insulation with an outside lead covering. The best way of applying the insulation would be so that every part were equally stressed. This ideal cable is impossible with the limited number of k values. The more nearly this condition is realized the higher the voltage that may be applied to the cable without rupture.

FIG. 19.



Case 1.—If insulation A, B, or C is used alone the breakdown voltage,

$$e_1 = 75 \text{ kv.}$$

Case 2.—Using A next to the wire, then B, then C, in the proper proportions the rupturing voltage is

$$e_2 = 133 \text{ kv.}$$

Case 3.—Using them in the reverse order, C, B, A, the rupturing voltage is

$$e_3 = 63 \text{ kv.}$$

Fig. 20 shows the distribution of stress on different parts of the cable with the three combinations. The areas of the curves are proportional to the breakdown voltages. In Case 2 the insulation of high permittivity may be thought of stretching and putting

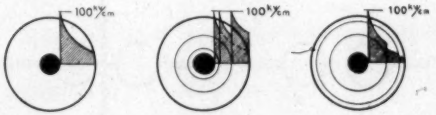
the stress on the electrically stiffer one B, and so on. In Case 3 the "stiffer" one is next to the conductor, and therefore takes most of the stress.

"Static" and "Leakage" over Insulation.

When one goes into a high-voltage station, sparking is often noticed around the metal parts, etc. This is generally called "static." It is really breakdown of the air caused by overflux density in the air near the metal part, as the metal parts are terminals for lines of force which extend from the high voltages, busses, etc.

Small "static" sparks are also often noticed at fairly low voltages between generator coils and the frame; in the air space between the central terminal and porcelain of a poorly-designed

FIG. 20.



Graded cable.

bushing where the weakest insulation and the one of lowest permittivity is often placed where the stress is the highest, etc. These sparks are caused by overflux density in the air. In the case of the bushing it is sometimes possible to prevent this by short-circuiting the flux through the air, by pasting tinfoil around the inner surface of the porcelain and connecting to the central rod. It is also now taken care of in the best modern high-voltage generators.

When tests are made on insulators or leads, a glow is often seen along the surface of the porcelain or at points on the porcelain. It is often spoken of as "leakage" over the surface. As a matter of fact, it is not really leakage, but due to overflux density in the air. What is called "leakage" or "creepage" over clean porcelain is really breakdown of the air part of the insulator. It is generally not realized that this air is as much a part of the insulator as the porcelain.

Dielectric Flux Control, Dielectrics in Multiple.

It is sometimes practical to accomplish more with metal than by added insulation. In a case where the field is not uniform, but very much more dense at one point than at another point, the flux may be made more uniform by relieving the dense portion and distributing over the less dense portion by a proper arrangement of metal parts connected to sources of potential of proper value. This is not always practical, as the necessarily complicated potential connections often weaken the apparatus and make it much more liable to breakdown. Metal shields and guard rings may often be used to advantage.

Apparatus must be designed to meet, not only normal conditions, but also, to a reasonable extent, abnormal conditions. Due to surges, lightning, arcing grounds, etc., high frequency, or impulses of steep wave front travel along the line and on reaching apparatus cause local potential rises. This must always be borne in mind. While under ideal normal conditions, with proper flux distribution, it is possible to make the dielectric very thin at points; potential may concentrate at these points at abnormal conditions and cause breakdown. When a dielectric circuit is made up of one dielectric, other dielectrics of different permittivities may be added without changing conditions of stress if added in multiple,—that is, shaped to follow the lines of force. This is, however, not always the best method of combining. Combination should be such as to relieve the weaker insulation and improve conditions by a distribution of stress on the different insulations in proportion to their respective strengths.

Effect of Altitude on Sparkover of Insulation and Bushings.

The apparent strength of air is reduced almost directly with its density. The density depends upon the temperature and barometric pressure. The density decreases as the temperature increases, and decreases very rapidly with the altitude. Suppose a transformer bushing or line insulator arcs over at 300 kv. where the barometric pressure is 75 cm. At a place where the barometer reads about 60 cm. this same bushing or insulator would arc over at approximately $\frac{60}{75} \times 300 = 240$ kv. The difference will generally be much less—depending upon design. At still higher altitudes the arc over voltage will be still less. It is, therefore,

very important to consider the altitude when designing high-voltage transformer leads, insulators, etc.

Methods of Measuring High Voltages.

The needle gap has long been used as a means of measuring high voltage and generally assumed to give correct results. This is not the case, especially at very high voltages, where the error is as much as 20 or 30 per cent.—the needle gap generally indicating higher voltages than really exist. This error is caused by variation due to humidity. There is also another cause of variation of which no mention is made in tables—that due to air density. Due to this cause, a needle gap unless correction is made indicates too high voltages at high altitudes.

The sphere gap is much more reliable.[5] There is no variation due to humidity, and the space factor is smaller than with needle gaps. The air density must, however, be corrected for—but this is fairly simple. It is not a direct function of air density, but also of the radius, as with corona on wires. The constants, however, are not the same. The apparent strength is:

$$g_s = g_o \delta \left(1 + \frac{k}{\sqrt{\delta R}}\right)$$

Altitude correction is easily made by arranging a table of correction factors for standard spheres at different altitudes.

The sphere should never be used at a spacing greater than $3R$, otherwise corona brush will form before spark-over. It is this brush that causes humidity variation on the needle gap. The gas in the air is probably precipitated to vapor, which has the effect of changing the point to approximate a sphere. The needle gap for this reason requires higher voltages to spark over a given gap at high humidity. The maximum voltages at sea level at which spheres of different diameters should be used on account of spacing is as follows:

Diameter, centimetres.	Grounded.	Non-grounded.
12.5	——	200
25.	320	380
50.	625	725
100.	1000	1500

[5] "The Sphere Gap as a Means of Measuring High Voltages" (F. W. Peek, Jr.), Discussion, *A.I.E.E.*, 1913; *G. E. Review*, May, 1913.

Probable Limits of Voltage in Transmission.

It is often asked, What will limit the voltages used in transmission? Transformers have been built and designed up to a million volts. For high voltages the line conductors must be large, otherwise there is a loss due to corona. A quarter of a million volts may be used (except at high altitudes) without excessive diameter or spacing. The line insulator is at present really a more serious limit than corona.[6] When the string of insulator units becomes long, the voltages along the string are not balanced, but tend to become higher across the units nearest the line. After a certain string length the addition of units helps very little. This may be pretty well eliminated by redesign. The most serious limit to the insulator, however, is the unreliability or uncertainty of porcelain. The replacement of broken-down insulators is bad, but, worse, every insulator that breaks down weakens the other insulators, transformers, etc., by the production of impulses, high-frequency oscillations, etc. It seems that the real limiting feature will be an economic one; the energy naturally concentrated at any given point will be exceeded by the demand in the surrounding country (except in rare instances) before the transmission distance becomes so great that voltages above the corona or insulator limit are necessary. It seems probable that the whole country could be tied together at about 200 kv. The energy transferred would be the excess at one point to take care of peak at another point, thus keeping the load factor high.

Voltage Regulation of Transmission Lines.

The actual effective voltage drop due to the reactance in the transmission line or transformer is very small if the power factor of the load is unity. If the power factor is lagging, this drop becomes very large, while if the power factor is leading, this drop is negative or actually adds to the voltage. Use is made of this fact in the control of the voltage. A synchronous motor, running light, is shunted across the line at the load end. If the voltage tends to drop by change of load, the field is changed so as to make the motor require current in the leading direction. If the voltage

[6] "Electrical Characteristics of the Suspension Insulator," *A.I.E.E.*, May, 1912.

tends to increase, the field of the motor is changed in the lagging direction. By this means the voltage at the load may be held constant without varying the generator voltage. In fact, the generator voltage is held constant automatically by a Tirrill regulator on the generator field, and the load voltage is held constant automatically by a Tirrill regulator on the synchronous motor field. It is possible by this method to hold the same voltage at both generator and receiving end.

By this means of control the carrying capacity of long-distance, high-voltage transmission lines may be doubled and perfect regulation secured at greater efficiency. Much money may often be saved in this way.

In very long distance, high-voltage lines the condenser or charging current may be as high as the load current. If the load is suddenly lost the voltage at the load end may double, due to this current. The synchronous condensers prevent this by requiring lagging current. In all very long lines this method of control has become a necessity.[7]

High Reactance in Transformers.

It is desirable to have high reactance in transformers and sometimes to even add external reactance to limit power during a short circuit. It has been objected that this reactance is undesirable from a standpoint of regulation. This is now generally not so. With synchronous motor or phase-control regulation discussed above, reactance is not generally undesirable, but often necessary.

Arcs and Short Circuits, High-voltage Switching.

Arcs and short circuits, high-voltage switching, etc., produce high-frequency oscillations and impulses of steep wave front. While these transients may in themselves generally not be of very high potential, they travel along the line and upon reaching a piece of apparatus containing inductance and capacity, as a transformer, build up very high voltage inside of the apparatus. This voltage does not appear across the line. The internal high-frequency voltage across a coil may be several times line voltage. A study

[7] "Practical Calculations of Long-distance Transmission Line Characteristics," *General Elect. Review*, June, 1913.

has made it possible to design apparatus in such a way as to limit such disturbances. A special form of protection has also been devised.

These impulses are also sometimes of high voltage, and line insulators may be weakened. It is thus of the greatest importance to see that line construction and insulators are of the very best, and to limit all operations which cause disturbance to the least required number. For this reason it is becoming the practice in modern lines to limit switching as much as possible—especially high-voltage switching. In fact, most of these lines will be arranged without high-voltage bus, and all switching done on the low side. The high side switches will generally be limited to disconnecting switches. A large generating plant will be paralleled on the low side with proper sectionalizing reactances in the bus. The several lines from the high side will be operated as separate systems.

As previously stated, the effect of such impulse voltages is cumulative—each impulse injures the insulation. Everything may thus be apparently all right for years and then a general breakdown may result.

In the above just a few of the problems and tendencies of high-voltage engineering have been touched upon as they have come to mind, without any attempt of going into detail.

The New Quartz-tube Mercury Arc Lamp. E. WEINTRAUB. (*Electr. World*, lxi, 984.)—Owing to the difference in the coefficients of expansion of quartz and platinum it is not possible to seal in platinum electrodes. Tungsten electrodes can be sealed in with a special borosilicate glass of high melting-point, and with a coefficient of expansion equal to 3.4×10^{-6}. This answers perfectly and renders it possible to use a higher temperature in the lamp without leakage. A current density three times that customary with platinum electrodes can be used, and the dimensions of the lamp are considerably reduced. The 110-volt lamp is only about 5 inches long. The use of tungsten also enables a solid anode to be used. This renders superfluous the complexities ordinarily considered necessary to balance the difference in evaporation of mercury at the electrodes. The lamps can be conveniently mounted in a vertical position so as to give a high horizontal illumination. The specific consumption of the 220-volt lamp is said to be 0.55 watt per mean spherical candle-power, the 110-volt lamp is rather less efficient. The lamp is being developed for use on alternating circuits and for series lighting.

Physiological Effects of Carbon Monoxide. A. S. MUNROE. (*Sch. of Mines Quart.*, xxxiii, 340.)—One of the most serious dangers from the presence of carbon monoxide in the air of mines is its effect on the health of the workmen who daily inhale small amounts of this gas. The blood, when partly saturated, is less able to perform its proper functions, so that the patient suffers from anæmia and the complications resulting from this weakened condition. According to Edsall, miner's phthisis is due chiefly to carbon monoxide poisoning. Recent observations have shown that for some hours after a blast, under ordinary mining conditions, carbon monoxide may be present in dangerous amounts, and undoubtedly men engaged in sinking, drifting, and stoping, where the circulation of air is deficient, have their blood partially saturated with carbon monoxide the greater part of the time. It is quite certain that dissociation of carbon monoxide from the blood is slow, and that those whose blood is partially saturated will sooner fall victims, where larger quantities of the gas are breathed, than those whose blood is untainted by it. Men who have repeatedly suffered, become very sensitive to the gas, and in most cases are compelled to abandon work in which they must inhale air containing it. The fact that the affinity of carbon monoxide for hæmoglobin is over two hundred times greater than that of oxygen, will give an idea of the slowness of its dissociation from blood containing it, and the great liability to its accumulation.

Determination of Critical Points Ar1 and Ac1 by a New Method. J. E. STEAD. (*Iron and Steel Inst.*, Sept., 1913.)—Two bars of the steel to be tested, conveniently measuring 115 x 10 x 5 mm., are supported out of contact with each other in a short porcelain tube, which is then inserted in the side of a muffle furnace, so that, while the inner ends of the bar are heated to about 1000° C., the outer ends remain well below 700° C. After about 30 minutes the temperatures, which have then become constant, are ascertained by introducing thin wires of silver, aluminum, zinc, etc., into the passage between the bars, and noting the points at which the wires fuse. A scale giving the temperature at each point along the bars can thus be plotted. The bars are removed, quenched, ground to remove the decarburized skin, immersed in dilute nitric acid, washed in water and alcohol, and dried. The hardened part is then seen to be quite black, while the soft part is gray, the plane of abrupt change indicating the critical point Ac1. A method of obtaining the points Ar1 and Ac1 at the same time is to heat two bars of the same steel together, and, after the temperature is constant, slowly to withdraw one bar for about 15 minutes, continue the heating for 15 or more minutes, and then, after taking the temperature readings, to quench and etch the bars. The withdrawn bar will give the point Ar1. It is stated that this method gives results within 3° C. of the truth.

PROPORTIONING OF LONG-SPAN TRUSS AND CANTILEVER BRIDGES.*

BY

JOSEPH MAYER.

Assistant Engineer, Quebec Bridge Commission, Montreal, Canada.

INTRODUCTION.

THE purpose of this paper is to describe a reliable method of finding the most economical general dimensions of long-span ordinary truss and cantilever bridges, and incidentally to give formulas which express their weight as a function of the loads, the unit stresses, and the general dimensions.

In the course of twenty-six years spent in designing bridges, among which were numerous long-span truss, cantilever, and suspension bridges, many rules for finding approximately the most economical dimensions and the weights of details were developed. This paper combines these rules into a logically connected whole and gives, where practicable, the mathematical reasons for them. The formulas are all given with their proofs, so that their truth can be easily tested.

Though many of the formulas appear, on first inspection, complicated, they permit the calculation of the weight of the longest cantilever bridge within a few days with reasonable accuracy, and make it thereby possible to compare the weights of designs with different general dimensions and to select the most economical shape of the trusses in a very short time.

Without such formulas the only practicable way to exactly compare the economy of different designs is by means of stress sheets and estimates which require often more time and labor than is available, and these estimates give very little indication how the general dimensions should be changed to secure the most economical design. The writer, therefore, believes that the method given in this paper is the only explicit method to attain this end, which is not based on mere trained feelings. These latter are only acquired after a lifetime of bridge calculation and are even

* Communicated by the author.

then only roughly approximate guides, reliable only within the range of the experience on which they are based.

MONTREAL, July, 1913.

ORDINARY TRUSSES

For the purpose of giving in a compact form the general course of the argument and its useful results the proofs for the formulas used are given in an appendix. The general method followed is to express the weight of the trusses and bracing as functions of the general dimensions of the trusses, the loads, and the unit stresses, and to show thereby the features that govern the weights.

The general formula for the total weight of steel of an ordinary truss span is:

$$W = 1.03\left[F + \frac{L^2}{1 - C_d L}\left\{\underset{\text{(i)}}{\mu C_\mu} + \underset{\text{(ii)}}{\frac{A_l L}{6}} + \underset{\text{(iii)}}{B_l} + \underset{\text{(iv)}}{C_d f}\right\}\right] \quad \ldots\ldots\ldots (1)$$

Where:

W = Total weight of steel of span.

F = Total weight of steel in floor.

L = Length of span centre to centre of end shoes in feet.

$$C_d = \frac{0.83}{12}(AL + 4B) \text{ for parallel chords} \quad \ldots\ldots\ldots\ldots (2)$$

$$Cd = \frac{0.73}{12}(AL + 4B) \text{ for curved top or bottom chords} \quad \ldots\ldots (3)$$

$$A = \frac{3.4}{h}\left\{\frac{a_t}{U_t} + \frac{a_c}{U_c}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

For B take

Bv with vertical posts. See (12).

Bi with inclined posts. See (13).

Bk with K-system of web members. See (14).

h = Height of trusses centre to centre of parallel chords.

h = 0.93 × height centre to centre of chords at centre of span with curved top or bottom chords.

Take $h = \frac{L}{6}$ for a double-track railway and highway bridge carrying Cooper's E 55 load on each railway track and highways equivalent to one railway track with Cooper's E 55 load.

$h = \frac{L}{8}$ for a highway bridge with the load on the trusses equivalent to that with a railway track with Cooper's E 18.3 load.

For a bridge with the load on the trusses equivalent to that from one track with Cooper's E p load take

$$h = \frac{L}{8}\left(1 + \frac{1}{3}\,\frac{p - 18.3}{146.7}\right) \quad \ldots\ldots (5)$$

$$a_t = \frac{\text{Weight of one panel of tension chord}}{3.4 \times \text{its required net area in square inches} \times \text{length of chord for one panel in feet}} \quad \ldots\ldots (6)$$

$$a_c = \frac{\text{Weight of one panel of compression chord}}{3.4 \times \text{its required gross area in square inches} \times \text{length of chord for one panel in feet}} \quad \ldots\ldots (7)$$

$a_t \backsimeq 1.25 \backsimeq a_h$ for eyebars.

$\backsimeq$ signifies "is approximately equal to."

The exact values of a_t and a_h (see below) can be found when the length and width of the bars and the diameters of the pins are known.

$a_t \backsimeq 1.5$ for riveted latticed tension members.

$a_c \backsimeq 1.45$

$U_t = 20{,}000$ = axial unit stress in tension chord from (dead + live + wind) stress for carbon steel.

$U_c = 14{,}000 - \sigma_b$ = axial unit stress in compression chord for

$$\frac{l}{r} < 50 \quad \ldots\ldots (8)$$

where l = length between supports

and r = least radius of gyration of cross section.

$$U_c = 17{,}500 - 70\,\frac{l}{r} - \sigma_b \text{ for carbon steel} \quad \ldots\ldots (9)$$

σ_b = bending stress due to weight of member.

$$\sigma_b \backsimeq \frac{l^2}{1.2e} \cos\delta \quad \ldots\ldots (10)$$

for continuous top chords where e = distance of extreme fibre in vertical plane from neutral axis, l and e both in feet and σ_b in pounds per square inch.

δ = angle of chord with horizontal.

$\sigma_b \propto \frac{l^2}{0.8e} \cos \delta$ for discontinuous chords with two pin ends... (11)

$$B_v = 4 \left\{ \frac{2\, a_{t1}}{U_{t1} \sin 2\beta} + \frac{a_{c1}}{U_{c1} \tan \beta} \right\}$$

for vertical posts as in Fig. 1 (*a*).....(12)

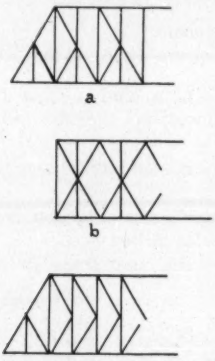
$$B_i = \frac{4.25}{\sin 2\beta} \left\{ \frac{a_{t1}}{U_{t1}} + \frac{a_{c1}}{U_{c1}} \right\}$$

for inclined posts as in Fig. 1 (*b*).....(13)

$$B_k = 3.75 \left\{ \frac{a_{t1}}{U_{t1}} + \frac{a_{c1}}{U_{c1}} \right\} \left\{ \frac{1}{\sin 2\beta} + \frac{1}{2 \tan \beta} \right\}$$

for K-system of web members as in Fig. 1 (*c*) ..... (14)

FIG. 1.



$a_{t1} \propto 1.25$; $a_{c1} \propto 1.50$

U_{t1} and U_{c1} are the unit stresses of web members for tension and compression respectfully.

For eyebars $U_{t1} = U_t = 20{,}000$

For riveted tension members $U_{t1} = U_t = 18{,}000$

$U_{c1} = 17{,}500 - 70 \frac{l}{r} - \sigma_b$ for $\frac{l}{r} > 50$..... (15)

$$U_{c_1} = 14{,}000 - \sigma_b \quad \text{for} \frac{l}{r} < 50 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

$$\sigma_b \infty \frac{l^2}{0.8e} \cos \delta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

l = length between supports, e = distance from neutral axis to extreme fibre measured in vertical plane, both in feet.
δ = angle of post with horizontal
β = angle of post with vertical
$\beta = 90 - \delta$

$$\mu = m_r (1 + I) + m_h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

m_r = uniform moving load per lineal foot of bridge, giving the same weight of chords as the actual railway moving load; this is approximately the uniform moving load per foot which gives at a distance of ¼ the span from its end the same moment as the actual load, or

$$m_r = \frac{32 M_{r\frac{L}{4}}}{3 L^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

where $M_{r\frac{L}{4}}$ is the moment of the actual load at a distance $\frac{L}{4}$ from the end of the span.

$$I = \frac{\text{impact stress}}{\text{railway moving load stress}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

No impact should be taken for highway load m_h.

$$\text{Take } I = \frac{300}{L + 300} \text{ for single track} \ldots\ldots\ldots\ldots\ldots\ldots (21)$$

$$I = \frac{300}{2L + 300} \text{ for double track} \ldots\ldots\ldots\ldots\ldots\ldots (22)$$

For calculating the sections of the stringers, floor beams, floor-beam hangers, and the truss members carrying one panel or less take

$$i = \frac{300}{\lambda + 300} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

where λ = length of loaded track giving the maximum stress. In calculating the floor the moment and shear from the railway load should be multiplied by $(1 + i)$ and the moments and shears from highway load should be added without impact.

$$C_\mu = \frac{1}{12}(AL + 4B) \text{ for parallel chords} \quad \ldots\ldots (24)$$

$$C_\mu = \frac{0 \cdot 96}{12}(AL + 4B) \text{ for curved top or bottom chords} \quad \ldots\ldots (25)$$

$$A_l = \frac{3 \cdot 4}{B_r}\left\{\frac{a_l}{U_l} \cdot p_w^t + \frac{a_c}{U_c} \cdot p_w^c\right\} \quad \ldots\ldots (26)$$

B_r = width of bridge.

$$\text{Take } B_r = \frac{L}{20} \quad \ldots\ldots (27)$$

or more where required for clearance.

p_w^t and p_w^c are the wind pressures in pounds per lineal foot of span for the lateral system between the tension and compression chords of the main trusses respectively.

$$\text{Take } p_w^c = 150 + 0 \cdot 7L \quad \ldots\ldots (28)$$

$$p_w^t = 750 + 0 \cdot 7L \quad \ldots\ldots (29)$$

for double-track railway and highway through bridges carrying Cooper's E 55 load on each railway track and highways equivalent to one railway track with Cooper's E 55 load.

For deck bridges with these loads :

$$p_w^c = 750 + 0.7L \quad \ldots\ldots (30)$$

$$p_w^t = 150 + 0.7L \quad \ldots\ldots (31)$$

Take p_w^c and p_w^t half as large for a highway bridge with the load on the trusses equivalent to a railway track with Cooper's E 18.3 load.

For a through bridge with the load on the trusses equivalent to that from one track with Cooper's E p load take in through bridges.

$$p_w^c = (75 + 0.35L)\left(1 + \frac{p - 18.3}{146.7}\right) \quad \ldots\ldots (32)$$

$$p_w^t = (375 + 0.35L)\left(1 + \frac{p - 18.3}{146.7}\right) \quad \ldots\ldots (33)$$

For a deck bridge with this load take

$$p_w^t = (75 + 0.35L)\left(1 + \frac{p - 18.3}{146.7}\right) \quad \ldots\ldots (34)$$

$$p_w^c = (375 + 0.35L)\left(1 + \frac{p - 18.3}{146.7}\right) \quad \ldots\ldots (35)$$

$$B_l = \frac{6.8\, p_w a_l}{U_l \sin 2\,\beta_l} \quad \ldots\ldots (36)$$

$$p_w = p_w^c + p_w^t \quad \ldots\ldots (37)$$

Equation (36) is good only for rigid lateral diagonals.

$$a_l = \frac{\text{Weight of lateral diagonal strut}}{3.4 \times \text{its required gross section in square inches} \times \text{its length in feet.}} \quad \ldots\ldots (38)$$

U_l = Axial unit stress per square inch in lateral diagonal struts.

β_l = angle of lateral diagonal struts with a horizontal line normal to the length of the span.

$$U_l = 17{,}500 - \frac{70\, l}{r} - \sigma_b \quad \text{for } \frac{l}{r} > 50 \quad \ldots\ldots (39)$$

$$U_l = 14000 - \sigma_b \quad \text{for } \frac{l}{r} < 50 \quad \ldots\ldots (40)$$

For box section lateral diagonal struts made of 4 or 8 angles latticed on four sides with double system of laterals $a_l = 2.6$ for carbon steel, $a_l = 3$ for nickel steel.

For short spans where other kinds of rigid diagonal struts are used, a_l is smaller and must be specially determined.

The values given for a_t a_c a_{tl} a_{cl} and a_l were determined from designs for the Quebec bridge now under construction.

f = total weight of floor per lineal foot of bridge in pounds; includes track, flooring, snow and steel.

$$l = 27 + \frac{4L}{300} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (41)$$

l = economical average panel length in feet for a double track railway and highway bridge carrying Cooper's E 55 load on each railway track and highways equivalent to one railway track with Cooper's E 55 load.

Take ¾ as much for a highway bridge with the load on the trusses equivalent to that with a railway track with Cooper's E 18.3 load.

For a bridge with a load on the trusses equivalent to one track with Cooper's E p load take

$$l = \left(20.25 + \frac{L}{100}\right)\left(1 + \frac{1}{3} \cdot \frac{p - 18.3}{146.7}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (42)$$

In spans of less than 600 feet the panel length is best taken uniform. For longer spans it is advantageous to increase the panel length toward the centre of the span.

In the formula (1) for the total weight of steel in a truss span the factor 1.03 is introduced to cover the end shoes, which weigh about 3 per cent. as much as the steel of the rest of the bridge.

F, the weight of steel in the floor, must be found by designing and estimating the weight of the floor beams and stringers.

The four items in the $\left\{ \quad \right\}$ of the formula (1) give, if multiplied by $\frac{L^2}{1 - C_d L}$, different parts of the weight of the span.

Item (I), $$\frac{\mu C_\mu L^2}{1 - C_d L} = W_{\mu+d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (43)$$

gives the weight of the steel required in the trusses to resist the stresses from the moving and impact load plus the total weight of steel needed to carry it.

$$\mu C_\mu L^2 = \mu\left(\frac{AL^3}{12} + \frac{BL^2}{3}\right) = W_\mu \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (44)$$

for parallel chords is the weight of steel needed for meeting the direct stresses from the moving and impact load μ.

$\mu\frac{AL^3}{12}$ is the corresponding weight of steel in the chords; $\frac{\mu L^3}{12}$ is the moment area by load μ. The weight of steel in the chords to meet the direct moving load and impact stresses is therefore equal to "A" multiplied by the moment area due to load μ.

$\mu\frac{BL^2}{3}$ is the weight of steel in the webs to meet these direct stresses from the moving and impact load μ.

$\mu\frac{L^2}{3}$ is the shear area due to load μ. The weight of steel in the webs to meet these direct moving load and impact stresses is therefore equal to "B" multiplied by the shear area due to load μ.

Item (II)

$$\frac{\frac{1}{6}A_l L^3}{1 - C_d L}$$

gives the weight of steel required in the chords of the two lateral systems to resist the wind stresses plus the total weight of steel needed to carry it.

$$\frac{1}{6}A_l L^3$$

is the weight of steel in the chords of the two lateral systems required to meet the wind stresses.

Item (III)

$$\frac{B_l L^2}{1 - C_d L}$$

gives the weight of steel of the lateral diagonals and the cross bracing plus the weight of steel needed to carry it.

Item (IV)

$$\frac{C_d f L^2}{1 - C_d L}$$

gives the weight of steel needed to carry the floor.

An example will clearly show the procedure for finding the general dimensions and the approximate weight of a long truss span.

Example.—To find the best general dimensions and the approximate weight of a 700-foot span for a double-track railway with Cooper's E 55 load per track.

For finding the best average panel length we use formula (42). With $p = 2 \times 55 = 110$ we obtain $l = 32.93$ feet.

This gives 21 panels.

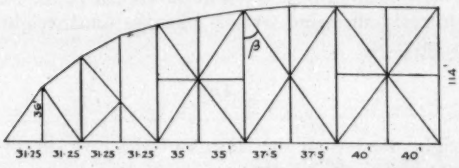
Formula (5) gives $h = 105.75$.

$$\frac{h}{0.93} = 113.7 = \text{maximum height.}$$

At the end posts we need adequate height to make a good portal. For this purpose 36 feet is adequate.

Twenty-one panels are not convenient. If we choose 20 panels and 114 feet maximum height with parabolic top chord we obtain with the panel lengths shown in Fig. 2, a diagram

FIG. 2.



which gives nearly uniform angles β slightly smaller than 45°, and which is the most economical design or very nearly so. Twenty-two panels might be slightly more economical, but the

difference would be small and could only be found by actually designing both spans.

The weight of this span is given approximately by the general formula (1).

The h to be used in finding A and B is not the height at centre, but 0.93 × this height = 106 feet.

The panel length to be used in the calculation of the weight is the average panel length

$$\frac{700}{20} = 35 \text{ feet}$$

We find

$$\tan \beta = \frac{70}{106} = 0.742$$

$$\beta = 36°34'30'' \quad 2\beta = 73°9' \quad \sin 2\beta = 0.957$$

The weight of the steel in the floor is found to be 1,100,000 pounds = F.

For the total weight of floor per lineal foot of bridge, we find f = 2570 pounds. Of this, 1000 pounds is the weight of the two tracks and 1570 pounds the weight of the steel.

$$U_c = 14{,}000 - \sigma_b$$

$$\sigma_b = \frac{35^2}{1.2e} = 500 \qquad \text{from (10)}$$

$$\therefore U_c = 13{,}500$$

$$U_{c_1} = 12{,}000$$

$$I = \frac{300}{1700} = 0.1765 \qquad \text{from (22)}$$

$$1 + I = 1.1765$$

$$m_r = 11{,}340$$

$$\mu = 11{,}340 \times 1.1765 = 13{,}340$$

$$A = \frac{3.4}{106}\left\{\frac{1.24}{20{,}000} + \frac{1.45}{13{,}500}\right\} = 5.434 \times 10^{-6}$$

from (4)

$$B_v = 4\left\{\frac{2.48}{20{,}000 \times 0.957} + \frac{1.5}{12{,}000 \times 0.742}\right\} = 1192.4 \times 10^{-6}$$

from (12)

$$C_d = \frac{0.73}{12}\left\{5.434 \times 700 + 4 \times 1192.4\right\} 10^{-6} = 521.5 \times 10^{-6}$$

from (3)

$$C_d L = 0.36505 \; ; \; 1 - C_d L = 0.63495$$

$$B_r = 35 \text{ feet} \; ; \; \tan \beta_l = 1 \; ; \; \beta_l = 45^\circ$$

$$C_\mu = 0.08 \times 8573.4 \times 10^{-6} = 685.87 \times 10^{-6}$$

from (25)

$$\mu C_\mu = 13{,}340 \times 685.87 \times 10^{-6} = 9.15$$

$$p_w^c = \left(75 + 0.35 \times 700\right)\left(1 + \frac{91.7}{146.7}\right\} = 520$$

from (32)

$$p_w^t = \left(375 + 0.35 \times 700\right)\left(1 + \frac{91.7}{146.7}\right) = 1000$$

from (33)

$$A_l = \frac{3.4}{35}\left(\frac{1.24}{20{,}000} \cdot 1000 + \frac{1.45}{13{,}500} \times 520\right) = 0.01145$$

from (26)

$$B_l = \frac{6.8 \times 1520 \times 2.6}{13{,}000 \times 1} = 2.067$$

$$C_d F = 521.5 \times 10^{-6} \times 2570 = 1.340$$

$$\frac{1}{6} A_l L = \frac{0.01145 \times 700}{6} = 1.336$$

$$W = 1.03\left[1{,}100{,}000 + \frac{490{,}000}{0.63495}\left\{9.15 + 1.336 + 2.067 + 1.34\right\}\right.$$

$W = 12{,}180{,}000$ pounds = total weight of steel in 700-foot span.

$\frac{W}{L} = 17{,}400$ pounds per lineal foot of span.

Of this 16,900 are distributed over the span. The rest is the weight of the shoes.

The proper dead load to use for the stress sheets is 17,900 pounds per foot of bridge.

If the trusses and bottom laterals were made of nickel steel, 50 per cent. stronger than carbon steel, we would obtain:

$$U_c = 21{,}000 - \sigma_b$$

$$\sigma_b = 600$$

$$U_c = 20{,}400$$

$$U_t = 30{,}000 = U_h$$

$$U_{c_1} = 17{,}000$$

$$A = \frac{3.4}{106}\left(\frac{1.24}{30{,}000} + \frac{1.45}{20{,}400}\right) = 3.606 \times 10^{-6}$$

$$B_v = 4\left(\frac{2.48}{30{,}000 \times 0.957} + \frac{1.5}{17{,}000 \times 0.742}\right) = 821.1 \times 10^{-6}$$

$$C_d = \frac{0.73}{12}\left\{3.606 \times 700 + 3284.4\right\}10^{-6}$$

$$= 353.3 \times 10^{-6}$$

$$C_dL = 353.3 \times 10^{-6} \times 700 = 0.2473$$

$$1 - C_dL = 0.7527$$

$$C_\mu = 0.08 \times 5808.6 \times 10^{-6}$$

$$= 464.69 \times 10^{-6}$$

$$\mu C_\mu = (13{,}340 \times 464.69 \times 10^{-6}) = 6.20$$

$$A_l = \frac{3.4}{35}\left\{\frac{1.24}{30{,}000} \times 1000 + \frac{1.45 \times 520}{20{,}600}\right\} = 0.00757$$

$$B_l = \frac{6.8 \times 1520 \times 3}{20{,}000} = 1.5504$$

$$\frac{1}{6}A_lL = \frac{0.00757 \times 700}{6} = 0.8832$$

$$W = 1.04\left[1{,}100{,}000 + \frac{490{,}000}{0.7527}\left(6.20 + 0.883 + 1.55 + 1.34\right)\right]$$

$W = 7{,}900{,}000$ pounds. Of this the floor, the top laterals, the cross bracing, and the shoes are carbon steel, the remainder nickel steel.

Since the shoes are carbon steel and a large part of the span nickel steel, the 3 per cent. does not hold true.

There are approximately 2,200,000 pounds of carbon steel and 5,700,000 pounds of nickel steel, against 12,180,000 pounds carbon steel in the first design.

It is evident that the second design is cheaper.

If the prices of the two steels are given, a short calculation shows which should be used for the floor.

The method of procedure here advocated will greatly abbreviate the finding of the best design and the selection of the proper dead load for the stress sheet. Different designers will find with different specifications slightly different coefficients α and different weights for the shoes, and they will have to determine the exact value of the coefficients from their own designs.

The correctness of the empirical formulas for the best panel length and the best height, as well as for the wind pressure to be assumed, can be tested from actual designs.

The proofs for the theoretical formulas are given in Appendix A.

CANTILEVER BRIDGES.

We found for ordinary trusses with parallel chords that the weight of the chords required by the moving load and impact stresses of a load $m_r + m_h$ where m_h is the highway load and m_r the equivalent uniform railway load, both per foot of bridge, is equal to A multiplied by the moment area of the load.

$$A = \frac{3.4}{h}\left(\frac{\alpha_t}{U_t} + \frac{\alpha_c}{U_c}\right) \qquad (4)$$

The load $m_r + m_h$ was replaced by a uniform load μ, giving the same total weight of chords as called for by the highway load m_h, the railway load m_r, and the impact produced by the latter.

The weight of the web required by the moving load and impact stresses of the load $m_r + m_h$ was found to be equal to the shear area of load μ per lineal foot of bridge multiplied by B.

B is different, according to the nature of the web system. Three main web systems were considered,—one with vertical posts, one with inclined posts, and one with K system.

The corresponding values of B were called B_v, B_i, B_k.

We found:

$$B_v = 4\left(\frac{2a_{h_1}}{U_{h_1}\sin 2\beta} + \frac{a_{c_1}}{U_{c_1}\tan\beta}\right) \quad \ldots\ldots (12)$$

$$B_i = \frac{4.25}{\sin 2\beta}\left(\frac{a_{h_1}}{U_{h_1}} + \frac{a_{c_1}}{U_{c_1}}\right) \quad \ldots\ldots (13)$$

$$B_k = 3.75\left(\frac{a_{h_1}}{U_{h_1}} + \frac{a_{c_1}}{U_{c_1}}\right)\left(\frac{1}{\sin 2\beta} + \frac{1}{2\tan\beta}\right) \quad \ldots\ldots (14)$$

These formulas also give the weight of the chords and the webs of a cantilever arm with parallel chords required for the moving load and impact stresses of the load $m_r + m_h$, as is apparent from their derivation given in Appendix A. μ is in this case the uniform load giving the same total weight of the chords of the cantilever arm as the actual load $m_h + m_r$ with the impact of m_r. With given height, panel length, and unit stresses, the weight of the trusses required for the stresses from moving load and impact is, therefore, governed by the moment and shear areas of the uniform load μ per lineal foot of bridge. These should, therefore, be made as small as possible.

In a cantilever bridge with a main span of length L, a suspended span of length l_s, two cantilever arms each of length l_c, and two anchor arms of length l_a, the moment area of the suspended span for a unit load per foot of bridge is

$$M_s^a = \frac{l_s^3}{12}\ ;\ \text{its shear area is}\ S_s^a = \frac{l_s^2}{3}$$

The moment area of one cantilever arm is

$$M_c^a = \frac{l_s l_c^2}{4} + \frac{l_c^3}{6}$$

The shear area of one cantilever arm is

$$S_c^a = \frac{l_s l_c}{2} + \frac{l_c^2}{2}$$

The moment area of the main span is

$$M_L^a = \frac{l_s^3}{12} + \frac{l_s l_c^2}{2} + \frac{l_c^3}{3}$$

The shear area of the main span is

$$S_L^a = \frac{l_s^2}{3} + l_s l_c + l_c^2$$

The moment area of anchor arm is

$$M_a^a = \frac{l_c\,(l_s + l_c)\,l_a}{4}$$

The shear area of anchor arm is

$$S_a^a = \frac{l_c\,(l_s + l_c)}{2} + \frac{l_a^2}{6}$$

A short anchor arm with a total anchorage pull positive for all positions of the moving load is assumed.

The total moment area of the three spans is:

$$M_b^a = \frac{l_s^3}{12} + \frac{l_c^2\,(3l_s + 2l_c)}{6} + \frac{l_c\,(l_s + l_c)\,l_a}{2}$$

The total shear area of the three spans is

$$S_b^a = \frac{l_s^2}{3} + 2l_c\left(l_s + l_c\right) + \frac{l_a^3}{3}$$

The formulas for M_b^a and S_b^a show that the least weight of trusses for moving load and impact is obtained when l_a is a minimum.

The anchorage stress from unit moving load per foot of bridge is

$$S_a^{end} = l_c\left(\frac{l_s + l_c}{2l_a}\right)$$

The anchorage stress is a load resisted by the anchorage and carried by the main pier. A short anchor arm gives large anchor stress. This calls for large main piers and large anchor piers and anchorages.

To avoid excessive cost of these, anchor arms about five-sixths as long as the cantilever arms are generally found economical, unless the profile of the river suggests a longer anchor arm to obtain a better site for the anchor piers. The length of the suspended span giving the least moment area of bridge is:

$$l_c = \frac{L - l_a}{4}$$

If $l_a = \frac{5}{6} l_c$, we obtain $l_c = \frac{6}{29} L$.

The moment area is a maximum for $l_s = 0$.

The shear area of the bridge is also a maximum for $l_s = 0$, and constantly decreases with increase of l_s until $l_s = L$.

When the suspended span is erected by building out from the ends of the two cantilever arms there arise with long main and long suspended span large erection stresses which govern the sections required in the ends of the cantilever arms and demand large increases in their weight to meet them.

With this method of erection

$$l_s = l_c = \frac{L}{3}$$

gives the most economical bridge for very long main spans.

If the suspended span is erected independently and floated into position, which is for long main spans often the most economical procedure and materially shortens the time required for erection, a considerably longer suspended span becomes economical, especially when the length of the main span is much less than the practical maximum of 1800 feet.

The formula

$$l_c = \frac{L - l_a}{4}$$

for the length of the cantilever arms which gives the smallest moment area of bridge for the moving and impact loads does not

apply to the moment area of the dead load. In very long spans the dead loads are most important and the moment areas of the dead load are smaller for longer cantilever arms.

To find the best length of the suspended span, the weight of the bridge for several lengths of the suspended span should be calculated by the formula hereafter given, and the length which gives, considering the cost of erection, the cheapest bridge should be chosen, unless æsthetic considerations govern.

For

$$l_c = l_s = \frac{L}{3} \text{ and } l_a = \frac{5}{6} l_c = \frac{5}{18} L$$

we obtain for the moment area of the bridge for a unit moving load per lineal foot $M_b^a = 0.778 \frac{L^3}{12}$

For the corresponding shear area we find

$$S_b^a = 1.521 \frac{L^2}{3}$$

The anchorage tension is

$$S_a^{end} = \frac{2}{5} L$$

For the main span the moment area is

$$M_L^a = \frac{11}{27} \frac{L^3}{12}$$

The shear area is

$$S_L^a = 0.778 \frac{L^2}{3}$$

For the same three ordinary independent truss spans the moment and shear areas from unit load per foot are:

$$M_{Bi}^a = 1.043 \frac{L^3}{12}$$

$$S_{Bi}^a = 1.1543 \frac{L^2}{3}$$

A comparison of the moment and shear areas of the three spans built as a cantilever with those when built as independent spans shows that for the moving load stresses a cantilever bridge offers no apparent advantage over independent spans. For short spans, where the moving load stresses are most important, independent spans are equally economical.

For certain situations, where a scaffolding is expensive or impossible, the easier erection of the main span of a cantilever bridge will give it decided advantage.

In long spans the dead load stresses are the most important, and of these those from the dead loads of the main span. In a bridge of three independent spans the dead loads are nearly uniformly distributed over each span. In a cantilever bridge of three spans the dead loads are mainly near the two piers carrying the main span. The moment and shear areas from dead loads are, therefore, very much smaller than those from an equal amount of uniformly distributed load. This advantage is of increasing importance with increase in the length of the main span.

Independent spans of more than 700 feet are, therefore, seldom advisable.

Definite information on these subjects is best obtained by means of formulas for the weight of steel in a cantilever bridge as a function of the load, the general dimensions, and the unit stresses.

The suspended span is an independent span for which the formulas have been already given. For the cantilever arms we have:

Weight of steel of one cantilever arm with parallel chords:

$$W_p^c = W_\mu + W_\mu^{d_1} + W_\mu^{d_2} + W_\mu^{d_3} + W_\omega + W_\omega^{d_1} + W_\omega^{d_2} + F + W_f^{d_1} + W_f^{d_2} + R \quad \ldots\ldots\ldots\

m_r is approximately the uniform moving load giving the same moment at the distance $\frac{2}{3} l_c$ from the end of the cantilever arm as the actual railway load.

$$\mu = m_r (1 + I) + m_h \quad \ldots\ldots (47)$$

$$I = \frac{300}{300 + l_s + l_c} \text{ for single track} \quad \ldots\ldots (48)$$

$$I = \frac{300}{300 + 2 (l_s + l_c)} \text{ for double track} \quad \ldots\ldots (49)$$

l_c = length of cantilever arm

l_s = length of suspended span.

For A and B see equations (4), (12), (13), and (14).

$$W_\mu^{d_1} = \frac{\mu V l_c}{240} \Big[A l_c^2 \{ A l_c (2 l_c + 5 l_s) + 20 B (l_c + 2 l_s) \} + 20 B^2 l_c (2 l_c + 3 l_s) + \frac{60 W_s}{\mu} (A l_c + 2 B) \Big] \quad \ldots\ldots (50)$$

$W_\mu^{d_1}$ = weight of steel in the cantilever trusses required to carry W_μ and W_s

$$V \sim 0{\cdot}97$$

W_s = Total weight of suspended span.

$$W_\mu^{d_2} = \frac{\mu V^2 l_c^3}{240} \Big[\frac{A^3 l_c^3}{42} (2 l_c + 7 l_s) + A^2 B l_c^2 (l_c + 3 l_s) + 3 A B^2 l_c (2 l_c + 5 l_s) + 10 B^3 (l_c + 2 l_s) + \frac{5 W_s}{\mu l_c} (A^2 l_c^2 + 8 A B l_c + 12 B^2) \Big] \quad \ldots\ldots (51)$$

$W_\mu^{d_2}$ = weight of steel in the cantilever trusses required to carry $W_\mu^{d_1}$

$$W_\mu^{d_3} = \frac{\mu V^3 l_c^4}{240 \times 168} \Big[\frac{A^4 l_c^4}{18} (2 l_c + 9 l_s) + 4 A^3 B l_c^3 (l_c + 4 l_s)$$

$$+ 24\,A^2\,B^2 l_c^2\,(2l_c + 7l_c) + 224\,AB^3 l_c\,(l_c + 3l_s)$$
$$+ 168\,B^4\,(2l_c + 5l_s) + \frac{28\,W_s}{\mu l_c}\left\{A^2 l_c^2\,(Al_c + 18B)\right.$$
$$\left. + 30B^2\,(3Al_c + 4B)\right\}\Bigg] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (52)$$

$W_\mu^{d_2}$ = weight of steel in the cantilever trusses required to carry $W_\mu^{d_2}$

$$W_\omega = \frac{6.8\,\alpha_c\,l_c^2}{24\,B_r\,U_c}\left\{6p_{ws}\,l_s + l_c\,(4a + bl_c)\right\} + \frac{3.4\,\alpha_l\,l_c}{U_l \sin 2\beta l}\left\{3p_{ws}\,l_s + l_c\,(3a + bl_c)\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (53)$$

$W\omega$ = weight of steel in the laterals and cross bracing of one cantilever arm. This includes the steel in the chords of the main trusses to resist the wind stresses in them.

B_r = breadth or width of bridge.

$p_{ws} = p_w$ of suspended span given in the equations (32) to (37).

a = wind pressure per lineal foot of bridge at end of cantilever arm

$$a \backsim p_{ws} \qquad b \backsim 1$$

$p_{wc} = a + bx$ = wind pressure per foot of cantilever arms at the distance x from its end.

$\alpha_l = 2.6$ for carbon steel, $\alpha_l = 3.0$ for nickel steel, both with lateral and cross bracing diagonal struts made of four or eight angles latticed on four sides.

$\alpha_c = 1.45$ when full compression splices and lacing able to resist a cross shear = 2 per cent. of the axial stress is prescribed.

βl = angle of the laterals with the cross struts.

U_l = axial unit stress in the laterals.

U_c = axial unit stress in the bottom chords of the trusses of the cantilever arm.

$$W_{\omega}^{d_1} = \frac{VCl_c^3}{360}\left[Al_c\{15E + l_c(6a + bl_c) + 6B\{10E + l_c(5a + bl_c)\}\right]$$
$$+ \frac{VDl_c^2}{20}\left[Al_c\{10E + l_c(5a + bl_c)\} + 5B\{6E + l_c(4a + bl_c)\}\right] \quad (54)$$

$W_{\omega}^{d_1}$ = weight of steel in the cantilever trusses required to carry W_{ω}

$$C = \frac{3 \cdot 4\, a_c}{B_r U_c} \quad (55)$$

$$D = \frac{3 \cdot 4\, a_l}{U_l \sin 2\beta_l} \quad (56)$$

$$E = p_{\omega s} l_s \quad (57)$$

$$W_{\omega}^{d_2} = \frac{V^2 l_c^3}{720}\Big[A^2 l_c^2 [Cl_c\{E + \frac{l_c}{28}(8a + bl_c)\}$$
$$+ 6D\{3E + \frac{l_c}{7}(7a + bl_c)\}]$$
$$+ 4ABl_c[Cl_c\{3E + \frac{l_c}{7}(7a + bl_c)\}$$
$$+ 3D\{15E + l_c(6a + bl_c)\}]$$
$$+ 2B^2[Cl_c\{15E + l_c(6a + bl_c)\}$$
$$+ 18D\{10E + l_c(5a + bl_c)\}]\Big]$$

$W_{\omega}^{d_2}$ = weight of steel in the cantilever trusses required to carry $W_{\omega}^{d_1}$

F is the weight of steel in the floor of the cantilever arm.

$$W_f^{d_1} = \frac{Vfl_c^2}{6}(Al_c + 3B) \quad (59)$$

$W_f^{d_1}$ = weight of steel in the cantilever trusses required to carry the floor of the cantilever arm.

f = total weight of floor of the cantilever arm per lineal foot of its length (includes timber, snow, etc.).

$$W_f^{d_2} = \frac{V^2 fl_c^3}{120}\left[Al_c(Al_c + 10B) + 20B^2\right] \quad (60)$$

$W_f^{d_3}$ = Weight of steel in the cantilever trusses required to carry $W_f^{d_1}$.

The coefficient V varies slightly with different engines and different specifications regarding the position of the engines in the train and with the web systems $V \infty 0.97$.

R = a rest to cover the weight of steel in the cantilever trusses required to carry

$$W_\mu^{d_3} + W_\omega^{d_2} + W_f^{d_2} + R$$

The succeeding W_μ^d W_ω^d and W_f^d decrease in size. From the rate of decrease the member of each series following the last one given can be roughly estimated and the value R thereby approximately determined.

R is always small.

$$\alpha_c = 1.45.$$

For eyebars, $\alpha_t = 1.25 = \alpha\, t_1$

This value of α_c assumes that the specification prescribes full splices in compression members and lacing able to carry a cross load equal to 2 per cent. of their axial stress.

The above formulas (45) to (60) are good for all values of l_s and l_c.

For $l_s = l_c = \frac{L}{3}$ the formulas are as follows:

$$W_\mu = \frac{\mu l_c^2}{12}\left\{5Al_c + 12B\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (46a)$$

$$W_\mu^{d_1} = \frac{\mu V l_c^3}{240}\left\{Al_c\,(7Al_c + 60B) + 100B^2 + \frac{60W_s}{\mu l_c^2}\,(Al_c + 2B)\right\} \quad (50a)$$

$$W_\mu^{d_2} = \frac{\mu V^2 l_c^4}{240}\left[\frac{A^2 l_c^2}{14}\,(3Al_c + 56B) + 3B^2\,(7Al_c + 10B) + \frac{5W_s}{\mu l_c^2}\,(A^2 l_c^2 + 8ABl_c + 12B^2)\right] \quad \ldots\ldots\ldots\ldots \quad (51a)$$

$$W_{\mu}^{d_1} = \frac{\mu V^3 l_c^5}{240 \times 168}\left[A^2 l_c^2\left(\frac{11}{18}A^2 l_c^2 + 20ABl_c + 216B^2\right)\right.$$
$$+ 56B^3(16Al_c + 21B) + \frac{28W_s}{\mu l_c^2}\left\{A^2 l_c^2(Al_c + 18B)\right.$$
$$\left.\left. + 30B^2(3Al_c + 4B)\right\}\right] \ldots\ldots\ldots\ldots\ldots\ldots (52a)$$

(53a) to (60a) are identical with (53) to (60).

CANTILEVER ARMS WITH INCLINED CHORDS.

To obtain simple formulas for the weight of such cantilevers we find first the formula for the weight of a cantilever truss with inclined chords carrying a uniform load per lineal foot, then that when carrying a load which increases uniformly from the end to the main pier. We then compare these weights for inclined chords with those for parallel chords, and we find that the weights of the cantilever with inclined chords can be obtained by finding the weights with parallel chords and multiplying them with coefficients given below.

$$W_s^c = 0.81\,W_{\mu} + W_{\omega}^{1} + F + 0.81\left\{0.81\,W_{\mu_1}^{d_1} + W_s^{d_1} + W_{\omega}^{1d_1}\right.$$
$$\left. + W_f^{d_1}\right\} + 0.81^2\left\{0.81 W_{\mu_1}^{d_2} + W_s^{d_2} + W_{\omega}^{1d_2} + W_f^{d_2}\right\}$$
$$+ 0.81^3\left\{0.81\,W_{\mu_1}^{d_3} + W_s^{d_3}\right\} + R \ldots\ldots\ldots\ldots\ldots (61)$$

Where $W_{\omega}^{1} W_{\omega}^{1d_1}$ and $W_{\omega}^{1d_2}$ are found by taking for $l_c - l_c \sec \delta_c$ in formulas (53) to (58)

$$W_{\mu_1}^{d_1} = \frac{\mu V l_c^2}{240}\left[Al_c\left\{Al_c(2l_c + 5l_s) + 20B(l_c + 2l_s)\right\} + 20B^2\right.$$
$$\left.(2l_c + 3l_s)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (50\,b)$$

$$W_s^{d_1} = \frac{Vl_c W_s}{4}\left(Al_c + 2B\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (50\,c)$$

$$W_{\mu^2}^{d_2} = \frac{\mu V^2 l_c^3}{240}\left[\frac{A^3 l_c^3}{42}(2l_c + 7l_s) + A^2 B l_c^2\ (l_c + 3l_s) + 3AB^2 l_c + (2l_c + 5l_s) + 10B^2\ (l_c + 2l_s)\right] \quad \ldots\ldots\ldots\ldots \quad (51\ b)$$

$$W_s^{d_2} = \frac{V^2 l_c^2 W_s}{48}\left(A^2 l_c^2 + 8ABl_c + 12B^2\right)$$

$$W_{\mu_1}^{d_3} = \frac{\mu V^3 l_c^4}{240 + 168}\left[\frac{A^4 l_c^4}{18}(2l_c + 9l_s) + 4A^3 B l_c^3 (l_c + 4l_s) + 24A^2 B^2 l_c^2\ (2l_c + 7l_s) + 224\ AB^3 l_c\ (l_c + 3l_s) + 168\ B^4\ (2l_c + 5l_s)\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (52\ b)$$

$$W_s^{d_3} = \frac{V^3 l_c^3 W_s}{1440}\left\{A^2 l_c^2\ (Al_c + 18B) + 30B^2\ (3Al_c + 4B)\right\} \quad (52\ c)$$

W_i^c = weight of cantilever arm with inclined chords when l_s and l_c are nearly alike and when the height at end is

$$h_e = \frac{h_p}{4.5} = \frac{l_c}{9}$$

h_p = height at main pier. These heights h_p and h_c are approximately the most economical heights for very long spans with independent erection of the suspended span and floating into position.

The suspended span will, in this case, be built with curved top or bottom chord.

A subdivided K system of web members is for the cantilever arms of very long main spans of 1200 to 1800 feet the most economical web system, and was here assumed.

W_i^c includes that part of the vertical posts above the main pier which is required for the loads coming from the cantilever arm, and it includes one-half of the cross bracing between these posts.

The height h which must be used for the calculation of A, B, and β is $0.344\ l_c = 0.688\ h_p$.

The cantilever arm with parallel chords, which is here used as a substitute for the actual arm with inclined chords, has equal panels.

The actual cantilever arm with inclined chords for a bridge with independent erection of the suspended span is for very long main spans of 1000 to 1800 feet best designed with panels increasing in length from the end to the main pier so as to obtain more nearly equal angles β for the diagonals. Panels 60 per cent. longer at the main pier than at the end of the cantilever arm are economical. The best average panel length for very long spans double track is

$$27 + \frac{4L}{300} \text{ feet.}$$

When the suspended span is erected by building out from the ends of the two cantilever arms it is best built with parallel chords and equal panels.

The cantilever arms have then less variation in height, and equal panels can be used without very much increase in weight.

The cost of erection is materially reduced by uniform panel length.

Formula (61) does not apply to a cantilever arm with this larger height at end. The coefficients are here different and are found in a similar manner as for a cantilever arm with smaller end height.

The formula for the weight of steel of a cantilever arm with

$$h_c = \frac{1.1L}{18} \text{ and } h_p = \frac{L}{6}$$

with a K system of web members and with equal panels of the most economical length is given below.

The formula is approximately correct also with other web systems and $h_p = 0.15L$ with proper choice of B.

For very long spans $l_s = l_c$; for shorter spans l_c is slightly smaller than l_s.

$$\begin{aligned} W_i^c = {} & 0.86\, W_\mu + W_\omega^1 + F \\ & + 0.86 \left\{ 0.86\, W_{\mu_1}^{d_1} + W_s^{d_1} + W_\omega^{1d_1} + W_f^{d_1} \right\} \\ & + 0.86^2 \left\{ 0.86\, W_{\mu_1}^{d_2} + W_s^{d_2} + W_\omega^{1d_2} + W_f^{d_2} \right\} \\ & + 0.86^3 \left\{ 0.86\, W_{\mu_1}^{d_3} + W_s^{d_3} \right\} + R \ldots\ldots\ldots \quad (61a) \end{aligned}$$

(To be continued.)

FURTHER EXPERIMENTS ON BISMUTH THERMOPILES.*

BY

WM. W. COBLENTZ, Ph.D.,

Associate Physicist, U. S. Bureau of Standards.

THE bismuth-silver thermopile appears to be winning a favorable place among the numerous devices employed in measuring radiant energy. The object of the present note is to describe experimental tests illustrating the shortcomings of some of the theoretical deductions relative to the construction of thermopiles.

1. *Relation between External and Internal Resistance.*—The older theories held that the maximum efficiency is attained when the external (the galvanometer) resistance is the same as the (internal) resistance of the thermopile. During recent years, however, Altenkirch [1] came to the conclusion, theoretically, that the external resistance can be two to three times the internal resistance of the pile, without seriously affecting its maximum efficiency. It therefore seemed desirable to subject the question to experimental test. In a previous paper [2] it was found, when the three units of a large surface thermopile were connected in series, thus producing an internal resistance which was about 6.4 times the external (galvanometer) resistance, that the radiation sensitivity was about two-thirds that of the thermopile having the units joined in parallel and having practically the same resistance as that of the galvanometer.

In the recent experiments the external resistance was greater than the internal resistance. In one outfit consisting of a galvanometer having four coils of 21 ohms resistance, and a thermopile having a resistance of 9.7 ohms, the radiation sensitivity was the same when the coils were in series-parallel (21 ohms) or all in parallel (5.3 ohms). The test was, of course, not very crucial, for it showed simply that when the external resistance was twice as great, or only half as great as the internal resistance,

* Communicated by the author.

[1] Altenkirch, *Phys. Zeitschr.*, 10, p. 560 (1909).

[2] Coblentz, *Bull. Bur. Standards* 9, p. 7 (1912).

the sensitivity was the same. The crucial test was made with a galvanometer consisting of 26-ohm coils mounted in the soft iron shields previously described.[3] This magnetic shield was sufficient to eliminate the ordinary magnetic disturbances and at the same time easily permitted the joining of the coils in various combinations: (1) all in series, (2) all in parallel, (3) two in series-parallel, giving 104, 6.5, and 26 ohms respectively. The thermopile was exposed to a standard of radiation[4] consisting of a seasoned incandescent lamp calibrated against a black body. Using a thermopile, having a resistance of 13.9 ohms, and an external resistance of 104 ohms, the radiation sensitivity was 31 per cent. less than when the external resistance was 26 ohms,—*i.e.*, the galvanometer resistance was respectively eight and two times that of the thermopile.

The most important test was with a thermopile having a resistance of 6.8 ohms. When the external resistance was four times (*i.e.*, 26 ohms) that of the thermopile the radiation sensitivity was 16.4 to 17 per cent. less than when the external resistance (6.5 ohms) was the same as the internal (thermopile) resistance. In view of the fact that there was a loss of only 16.5 per cent. in efficiency when the external resistance was four times the internal resistance, and in view of the fact that one rarely meets with conditions where the galvanometer resistance is more than twice the resistance of the thermopile, it is evident that this question proves to be of minor importance. Nevertheless, it was important to settle the question, for one of the first specifications of intending purchasers of these instruments is that the resistances of the two instruments must be equal.

2. *The Radiation Sensitivity of a Thermopile.*—The factors which determine the radiation sensitivity of a vacuum thermopile, as enunciated by Johansen,[5] are as follows: (1) The resistance of the thermopile should be equal to that of the galvanometer; (2) the radii of the two wires of the element should be so chosen that the ratio between the heat conductivity and the electrical resistance is the same in both; (3) the heat loss by conduction through the wires should be equal to the heat loss by radiation

[3] Coblentz, *Bull. Bur. Standards* 9, p. 7 (1912) (see Fig. 17).

[4] "A Secondary Standard of Radiation," JOUR. FRANKLIN INSTITUTE, 176, p. 219 (1913).

[5] Johansen, *Ann. der Phys.* (4), 33, p. 517 (1910).

from the junctions; (4) the radiation sensitivity is proportional to the square root of the exposed surface.

In previous papers [6] it was shown experimentally that rules (2) and (4) are only approximately true. In fact, the best diameter of silver wire (0.036 to 0.038 mm.) to be used with a 0.1 bismuth wire was found without considering the theory. In the same manner an iron wire 0.0308 mm. diameter was found better than one 0.0418 mm. in diameter, although theory would have required the thicker wire.

Rule (3) tells us nothing but what must be obtained by experiment, and that must be obtained on a complete thermopile. For example, one would naturally try to use flat bismuth wire to avoid heat conduction. The test, using a single pair of junctions, showed [7] that the flat wire gave a radiation sensitivity which was about 9 per cent. higher than that of a junction made of round wire. A thermopile was therefore constructed with the greatest care. It embodied the experience and improvements resulting from the construction of 21 thermopiles. It contained 28 elements; had an area of 2 by 14.5 mm. and a resistance of 13.5 ohms. It proved to be the quickest acting of all the instruments yet constructed, but its intrinsic radiation sensitivity (*i.e.*, sensitivity per mm.^{2} of exposed surface) was only 16.4, when all the others, similarly constructed, of round wires had a radiation sensitivity of 25.5 to 26.

The results showed that in smoking the thermopile the flat wires were given a different relation between the emissivity and conductivity than obtained in the round bismuth wires. Johansen's rule (3) was not fulfilled; and nothing but a prolonged experiment sufficed to determine the best mode of construction. The bismuth-silver thermopile is based upon experiment. Its novelty is the completely opaque receiver, while at the same time maintaining a symmetry of the hot and the cold junctions as found in the Rubens and older types of thermopiles.

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[6] Coblentz: *Bull. Bur. Standards* 9, p. 7 (1912). JOURNAL FRANKLIN INSTITUTE, 175, p. 497 (1913). *Physikalische Zeitschr.*, xiv, 683 (1913). *Jour. Wash. Acad. Sci.*, 3, p. 357 (1913). These experiments were made on thermopiles in air. There is a distinct field of investigations requiring thermopiles in air.

[7] Coblentz: *Phys. Zeitschr.*, xiv, 683 (1913). *Jour. Wash. Accd. Sci.*, 3, p. 357 (1913).

In some forms of thermopiles now being put on the market the cold junctions are attached to the metal supporters. This introduces a dissymmetry between the hot and cold junctions, and hence a likelihood of "drift" of the galvanometer needles. For the incident radiation warms the surrounding air, and the cold junctions, because of their greater heat capacity, cannot quickly take the temperature of the surroundings.

By making the small receivers twice as long and attaching two junctions to each receiver, less shellac is required for insulation between the hot junctions, and the heat capacity, the emissivity, and the resistance are reduced. A thermopile built on this principle, consisting of nine pairs of junctions joined in series-parallel, had a resistance of 2.2 ohms. If the 18 elements had been joined in series the resistance would have been four times as great. In this thermopile the receivers were 2 by 2.1 mm., making a completely opaque curtain 2 by 18.5 mm. in area. The device is more sensitive and quicker acting than the old style, and it was entirely free from drift.

The receivers are made of platinum, which remains bright on the rear, unprotected side, thus keeping a low emissivity. Silver receivers might be better when new, but eventually the rear (unprotected) side would become black, thus increasing the emissivity. The use of thin metallic receivers permits a modification of the device to suit the individual problem. For example, in a physiological problem involving the question of the heat produced in a stimulated nerve the receiver is built in the form of a long, U-shaped trough, 21.5 mm. in length, within and along the axis of which is suspended the sample under investigation. This thermopile receives heat by radiation and by conduction from the material placed within the U-shaped receiver. The sensitivity (approximate value) was tested by placing a silk-covered manganin wire (0.05 mm. diameter, resistance 4.5 ohms) within the receiver, and passing an electric current through it. Using a galvanometer sensitivity of 5×10^{-10} ampère, a deflection of 1 mm. $= 4.3 \times 10^{-8}$ watt, or 1×10^{-8} calorie was shown.

It is desirable to emphasize the importance of examining the electromotive force of the bismuth wire. Of the eight samples tested (diameters 0.06, 0.08, 0.1, and 0.15 mm.), the thermoelectric power, against silver, varied from 75 to 82 microvolts. This seems to depend upon the purity of the material, as indicated

by the purchases at different times. The material received in one order of 0.08 and 0.1 mm. bismuth wire gave 76 microvolts, while another order consisted of material giving 75 and 82 microvolts respectively.

The electromotive forces of various thermopiles, exposed to a standard of radiation, was measured with an ordinary potentiometer. The actual voltages developed varied from 6 to 20 microvolts (depending, of course, upon the number of thermojunctions, and especially upon the area exposed), which was equivalent to 0.20 to 0.25 microvolt per microwatt. One thermopile gave 0.35 microvolt per microwatt. The *efficiency* per single junction, in the thermopiles examined, varied from 0.011 to 0.014 microvolt per microwatt of radiant energy. Since the thermoelectric power is about 78 microvolts, the results show that 1 microwatt produces a rise in temperature of about $15^\circ \times 10^{-6}$ C. above the surrounding air. This seems the most logical way to rate the efficiency of a thermopile.

In most of the thermopiles there was but little gain by placing more than one thermojunction per 0.8 mm. length of the complete receiver, and ordinarily it would be sufficient to place them at a distance of 1.2 mm. length. This should be sufficient to give a correct integration of the incident radiation if it should not be uniformly distributed.

Recent investigations[8] show that an alloy of Bi + 9 per cent. Sb gives a higher electromotive force than pure bismuth; but this alloy is too brittle for thermopiles. The best combination which gives fine annealed threads, by spattering,[9] is Bi + 4 per cent. antimony. The electromotive force of the material must be tested, however, for some samples give a lower electromotive force than the best wire of pure bismuth.

An alloy of Bi + 5 to 6 per cent. tin gives 44 to 45 microvolts. When used with the best bismuth wire the thermal element

[8] Haken: *Ann. der Phys.* (4), 32, p. 291 (1910).
Gelhoff and Newmeier: *Verh. Phys. Gesell.*, 15, p. 876 (1913).

[9] Coblentz: *Bull. Bur. Standards* 7, p. 248 (1910). This method, which seemed too ridiculous for description at that time, is one of the chief contributions to the improvement of thermopiles. By dropping the molten metal from a height, upon an inclined glass plate, the metal is drawn out into thin, well-annealed threads. Pfund (*Phys. Rev.*, 34, p. 228, 1912) goes a step further, and hurls the molten metal against the glass plate. This produces longer threads, of great uniformity.

gives an electromotive force of 126 to 128 microvolts. An element consisting of pure bismuth wire and an alloy of Sb, Cd, Bi gave 138 to 140 microvolts per degree; but the alloy is too brittle for an ordinary thermopile. The most promising thermopile appears to be one having elements of pure bismuth and an alloy of Bi + 6 per cent. tin, joined in series-parallel, as already described.

In conclusion it may be added that in the discussion of theory *versus* experiment it is not intended to detract from the theoretical contribution to the subject. On the other hand, it is but fair to emphasize the contributions which had to be worked out experimentally. These experiments relate to the most crucial points in thermopile construction, especially the question of heat conduction and emissivity, upon which theory could be of little assistance.

WASHINGTON, D. C., October 25, 1913.

Natural Gaseous Mixtures Rich in Helium. C. MOUREU and A. LEPAPE. (*Compt. Rend.*, clv, 197.)—The following mineral springs evolve gas containing a large percentage of helium. The natural gas from the springs at Sautenay contains from 8.4 to 10.1 per cent. of helium, that from springs at Maiziéres contains 5.9 per cent.; from springs at Grisy, 2.18 per cent.; from Bourbon Lancy, 1.84 per cent.; from Néris, 0.97 per cent.; and from La Bourboule, only 0.1 per cent. The quantities are too large to be considered as nascent helium evolved immediately it is produced; and it is more probable that the immediate source is dissolved helium, evolved by the disintegration of minerals in which it has been absorbed. These sources are grouped in the neighborhood of Moulins, Dijon, and Vesoul.

Pressure-Balanced Piston Rings. ANON. (*Eng.*, cxv, 521.)—This paper describes piston rings by Allen and Simmons, Ltd., which are designed to decrease the friction of piston rings and, consequently, the lost power. The fundamental idea is to balance the outward radial pressure of steam behind the rings by giving them a suitable cross section. It is shown by calculation that, whereas the frictional losses caused by Ramsbottom rings might be 4.8 per cent., the loss with the Allen rings is only 0.173 per cent. The same idea is applied to piston valves, air-pump buckets, and gland packing. It is also shown that it is possible, by the use of Allen rings, to employ a very simple form of piston, which is cheaper to construct and is more efficient thermally than the ordinary type.

EVIDENCE BEARING ON THE SOLVATE THEORY OF SOLUTION.*

BY

HARRY C. JONES.

[The investigations referred to in this paper have been largely carried out with the aid of grants from the Carnegie Institution of Washington.

This paper has been written in response to a request from the Editor of the JOURNAL OF THE FRANKLIN INSTITUTE, to summarize for *this journal* the experimental evidence obtained in my laboratory, bearing upon the solvate theory of solution as it originated here about fourteen years ago.]

In the following tables, under λ are given the wave-lengths of light that were passed through the solution, and under I/I_0 the percentage of transmission, on the one hand, of the solution, and, on the other, of water having a depth exactly equal to that of the water in the solution.

The ordinates of the curve, as has already been stated, are percentage transmissions and the abscissæ wave-lengths.

TABLE I.

	KCl 4 N		NH_4Cl 4 N		NH_4NO_3 3.12 N	
λ	I/I_0	H_2O	I/I_0	H_2O	I/I_0	H_2O
710	97	97	92	98	95	98
724	96	95	91	96	97	98
741	95	95	90	92	96	96
760	93	95	85	92	91	95
776	92	95	85	88	92	94
798	94	95	88	95	91	95
818	92	95	87	95	92	96
836	94	93	87	95	91	94
855	91	90	86	93	89	92
878	92	90	86	91	90	93
900	90	89	84	87	89	88
922	87	86	82	86	85	90
947	82	84	79	82	82	83
958	77	78	73	72	73	79
964	75	73	69	70	70	71
969	65	65	64	63	65	67
974	58	56	57	58	58	59
979	51	50	52	52	50	54
982	47	46	45	46	44	46
985	41	45	43	43	40	44
991	39	43	41	43	39	43

* Concluded from page 564.

	KCl 4 N I/I_0	H_2O	NH_4Cl 4 N I/I_0	H_2O	NH_4NO_3 3 . 12 N I/I_0	H_2O
1007	39	43	41	42	39	44
1013	40	42	39	44	41	44
1019	42	46	40	46	42	44
1025	41	42	44	49	45	48
1032	49	49	44	49	48	49
1037	53	52	56	55	52	53
1042	56	56	53	58	55	55
1046	59	60	57	57	57	60
1059	63	62	58	65	60	65
1065	68	67	62	67	64	65
1072	71	68	64	68	66	69
1078	74	72	67	67	66	72
1085	75	73	67	66	68	74
1100	77	75	68	72	69	78
1113	76	76	69	72	69	78
1138	75	72	68	70	68	72
1148	70	69	64	65	64	71
1158	64	63	62	64	59	64
1165	58	59	58	58	56	60
1172	52	51	50	50	53	52
1179	42	40	40	40	38	41
1186	29	28	29	26	29	30
1193	18	19	19	19	18	19
1200	13	16	14	13	12	17
1206	10	12	12	12	9	13
1213	10	11	10	12	9	13
1220	10	11	10	11	9	12
1227	10	11	10	11	9	12

In the above table the depth of layer of all the solutions was the difference between 21 and 1,—*i.e.*, 20 mm. The depth of water was in every case the same as that of the water in the solution in question.

The depth of layer of the following solutions was the difference between 11 mm. and 1 mm.,—*i.e.*, 10 mm. The depth of water used was in every case the same as that of the water in the solution:

TABLE II.

	KCl 4 N I/I_0	H_2O	NH_4Cl 4 N I/I_0	H_2O	NH_4NO_3 3 . 12 N I/I_0	H_2O
1085	85	86	79	87	81	88
1100	87	88	80	92	81	93
1113	86	87	79	86	84	86
1138	81	85	79	84	81	84

	KCl 4 N I/I_o	H_2O	NH_4Cl 4 N I/I_o	H_2O	NH_4NO_3 3.12 N I/I_o	H_2O
1148	79	82	77	84	78	84
1158	80	79	74	81	76	81
1165	76	77	71	77	72	77
1172	72	71	66	70	67	70
1179	64	62	59	62	61	62
1186	51	51	52	50	50	50
1193	41	43	42	44	40	44
1200	35	38	37	40	34	40
1206	37	36	35	37	32	37
1213	30	34	30	36	32	36
1220	30	35	29	35	34	35
1227	30	34	30	35	32	35
1233	30	33	28	35	31	35
1241	30	34	29	34	31	34
1248	31	34	28	33	31	33
1250	33	34	30	34	32	34
1255	34	35	30	36	32	36
1268	34	35	31	37	32	37
1270	37	31	32	38	33	38
1285	38	38	33	38	33	38
1295	39	38	32	38	33	38
1300	41	38	32	39	34	39
1308	42	39	32	41	35	41
1316	41	39	32	40	34	40
1323	42	37	32	38	34	38
1330	40	37	32	37	33	37
1338	40	35	30	35	31	35
1346	36	33	28	36	30	36
1352	34	29	26	29	27	29
1358	29	26	23	27	25	27
1365	25	22	21	23	21	23
1372	20	18	17	20	17	20
1387	13	12	12	11	10	11
1404	7	7	7	8	7	8
1418	3	4	4	3	3	3
1430	2	2	3	2	2	2
1445	0	0	0	1	1	1

In Table II the depth of layer of the solution that was used was only half of that in Table I. The object of this was to bring out more prominently the second water-band.

The depth of layer of the following solutions was the difference between 21 mm. and 1 mm.,—*i.e.*, 20 mm. The depth of water used in every case was the same as that of the water in the solution:

TABLE III.

	$CaCl_2$ 5.38 N		$MgCl_2$ 4.96 N		$Al_2(SO_4)^2$ 1.02 N	
	I/I_o	H_2O	I/I_o	H_2O	I/I_o	H_2O
710	94	98	95	98	95	93
724	92	98	98	98	95	95
741	90	95	95	98	94	93
760	87	94	94	98	92	93
776	88	93	92	97	93	95
798	91	96	93	94	92	90
818	93	99	90	90	93	92
836	92	97	92	95	92	92
855	90	93	91	90	90	91
878	90	90	91	93	91	90
900	89	92	88	92	89	90
922	86	91	88	91	85	86
947	87	84	84	86	82	81
958	78	79	76	78	76	73
964	75	73	82	76	72	66
969	70	68	75	69	68	61
974	65	62	68	65	64	55
979	59	53	61	56	58	48
982	51	49	48	51	53	42
985	48	49	54	45	51	40
991	44	46	48	49	47	39
1007	42	46	46	48	46	38
1013	42	46	45	50	46	39
1019	43	49	44	51	44	40
1025	47	50	46	44	46	43
1032	52	53	51	54	46	45
1037	55	55	52	56	52	50
1042	58	59	56	58	53	53
1046	62	62	59	65	55	55
1059	66	65	63	67	55	58
1065	71	70	69	70	62	63
1072	74	72	71	75	60	65
1078	75	74	71	76	64	69
1085	78	76	76	79	65	70
1100	80	77	78	79	67	72
1113	79	78	80	81	67	74
1138	77	75	77	78	64	67
1148	74	71	75	77	60	65
1158	69	65	73	73	57	55
1165	66	62	65	65	55	53
1172	61	52	61	58	50	43
1179	54	41	52	44	45	34
1186	42	30	43	32	34	22
1193	32	21	32	24	25	15

	$CaCl_2$ 5.38 N I/I_o	H_2O	$MgCl_2$ 4.96 N I/I_o	H_2O	$Al_2(SO_4)_3$ 1.02 N I/I_o	H_2O
1200	22	17	23	18	20	12
1206	16	16	18	17	16	10
1213	13	15	16	18	14	9
1220	12	13	14	15	11	10
1227	12	13	14	16	12	8

In the following table the depth of layer used was the difference between 11 and 1 mm.,—*i.e.*, 10 mm. The object of using the smaller depth of the solution was to bring out more clearly, in the case of hydrated salts, the second water-band:

TABLE IV.

	$CaCl_2$ 5.38 N I/I_o	H_2O	$MgCl_2$ 4.96 N I/I_o	H_2O	$Al_2(SO_4)_3$ 1.02 N I/I_o	H_2O
1085	84	84	82	84	79	82
1100	84	84	83	84	78	81
1113	84	86	83	84	78	84
1138	86	85	82	83	77	83
1148	82	83	79	80	75	80
1158	80	79	77	77	73	77
1165	78	76	77	75	70	73
1172	76	72	74	70	66	69
1179	72	65	71	64	63	58
1186	63	55	62	52	55	48
1193	54	45	56	46	49	39
1200	45	40	48	42	43	34
1206	38	39	42	40	38	30
1213	35	39	39	38	36	29
1220	33	36	37	38	34	28
1227	32	36	36	38	32	28
1233	31	35	34	37	32	28
1241	32	35	34	34	31	28
1248	32	35	34	37	31	28
1250	33	35	34	38	31	28
1255	33	37	34	38	31	28
1268	35	38	33	38	30	29
1270	37	39	34	39	30	30
1285	38	40	35	40	30	31
1295	40	40	35	40	30	32
1300	42	41	36	41	30	32
1308	42	41	37	42	30	33
1316	45	41	39	42	30	33
1323	47	40	39	41	28	33
1330	46	39	40	40	27	32
1338	45	37	38	38	27	30

	$CaCl_2$ 5.38 N		$MgCl_2$ 4.96 N		$Al_2(SO_4)_3$ 1.02 N	
	I/I_o	H_2O	I/I_o	H_2O	I/I_o	H_2O
1346	42	35	38	36	24	27
1352	40	32	34	33	22	24
1358	37	29	33	30	20	21
1365	33	25	29	26	18	19
1372	29	21	25	22	15	15
1387	19	13	18	15	10	9
1404	12	10	12	11	7	5
1418	7	6	7	9	4	3
1430	3	3	4	3	2	2
1445	2	1	1	1	1	1

When salts which are strongly hydrated in aqueous solution are not very concentrated, the difference between the transparency of the salt solution and that of water of the same depth of layer as the water in the solution is not so pronounced. This is what would be expected; since the total amount of water combined with the dissolved salt increases with the concentration of the solution. The data given in the following table bring out this fact:

TABLE V.

	$CaCl_2$ 2.69 N		$MgCl_2$ 2.48 N		$Al_2(SO_4)_3$ 0.508 N	
	I/I_o	H_2O	I/I_o	H_2O	I/I_o	H_2O
710	96	94	95	95	97	96
724	95	96	93	96	98	96
741	95	95	90	95	95	93
760	94	96	92	95	95	95
776	93	97	93	95	95	95
798	90	98	91	95	96	96
818	93	97	91	93	95	90
836	91	96	89	93	93	95
855	91	92	88	92	92	92
878	90	92	84	90	90	91
900	88	90	84	88	89	86
922	89	92	81	86	82	85
947	82	86	78	83	78	80
958	75	79	72	76	73	75
964	70	74	70	73	68	69
969	65	69	62	64	62	62
974	58	61	58	58	57	54
979	50	52	50	51	50	46
982	44	47	46	46	46	42
985	40	43	42	43	43	40
991	39	41	40	41	41	39
1007	38	40	41	42	40	40

	$CaCl_2$ 2.69 N I/I_o	H_2O	$MgCl_2$ 2.48 N I/I_o	H_2O	$Al_2(SO_4)_3$ 0.508 N I/I_o	H_2O
1013	39	42	40	44	40	40
1019	40	43	40	44	41	41
1025	43	45	44	41	43	43
1032	45	47	47	44	45	46
1037	48	50	50	46	47	48
1042	51	52	52	48	49	49
1046	56	56	56	54	53	54
1059	61	59	58	55	60	59
1065	65	64	64	62	59	62
1072	69	67	67	64	63	65
1078	70	69	69	67	65	69
1085	72	72	72	68	68	72
1100	73	73	73	71	69	73
1113	72	74	74	72	68	74
1138	72	74	74	70	67	72
1148	66	69	69	67	64	67
1158	67	62	62	60	58	62
1165	57	58	58	58	54	54
1172	52	51	53	52	47	46
1179	46	39	42	42	39	35
1186	30	27	31	27	28	25
1193	20	19	21	20	20	16
1200	13	14	15	15	14	12
1206	12	11	12	13	12	10
1203	11	11	12	12	11	10
1220	11	10	11	11	11	10
1227	10	9	10	10	10	9

The depth of layer of the different solutions for which the results are recorded in the above table was the difference between 21 and 1 mm.,—*i.e.*, 20 mm. The results are, therefore, comparable with those recorded in Table III, the difference being a difference in the concentrations of the solutions used. It will be seen by a glance at the table, that the difference between the transmission of the solution and that of water of the same depth as the water in the solution, is very much less for the more dilute than for the more concentrated solutions. As has already been pointed out, this is exactly what would be expected in terms of the solvate theory applied to the phenomenon in question.

Considerable work was done in *comparing directly* the transmission of a solution, and that of water having the same depth as the water in the solution in question. The deflection of the

radiomicrometer as given by the solution is in the column marked "*I* sol.," and the deflection as given by water having the same depth as water in the solution is given in the column marked "I_0H_2O."

The results obtained for aluminium sulphate having a concentration 1.02 N, and for 4 N potassium chloride are given in the following table. The depth of solution used was 20 mm., and the depth of water that of the water in the solutions in question.

TABLE VI.

	I sol. $Al_2(SO_4)_3$	I_0 H_2O	*I* sol. KCl	I_0 H_2O
710	50	51	53	53
724	58	58	56	56
741	62	63	67	68
760	72	72	77	77
776	75	76	88	90
798	83	83	98	99
818	82	82	108	109
836	93	94	116	116
855	97	97	124	124
878	105	105	129	130
900	105	105	140	138
922	112	112	140	140
947	113	113	142	142
958	109	106	136	136
964	107	100	129	125
969	104	93	118	116
974	98	83	108	106
979	93	73	92	92
982	82	66	83	83
985	80	64	78	80
991	78	62	78	80
1007	78	65	78	81
1013	74	65	81	85
1019	77	68	84	88
1025	80	75	96	96
1032	84	77	100	101
1037	91	84	112	108
1042	92	92	119	116
1046	99	99	125	120
1059	105	105	141	136
1065	109	112	150	145
1072	114	119	159	153
1078	118	125	164	158
1085	122	132	168	164

	I sol. $Al_2(SO_4)_3$	I_0 H_2O	I sol. KCl	I_0 H_2O
1100	128	140	176	172
1113	129	142	178	175
1138	127	142	174	170
1148	123	131	164	162
1158	112	118	161	159
1165	108	111	157	154
1172	99	94	132	126
1179	87	74	107	100
1186	68	49	73	66
1193	54	35	50	48
1200	42	26	24	36
1206	35	23	39	34
1213	30	21	25	30
1220	28	20	24	29
1227	26	19	24	28
1241	24	19	23	26
1255	23	18	25	27

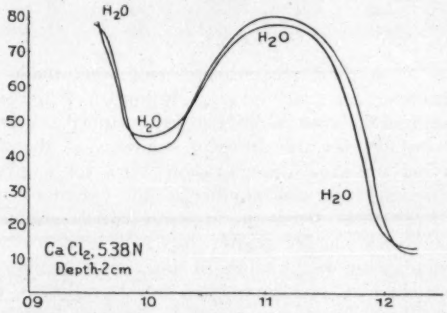
In this work duplicate measurements were made with the radiomicrometer for nearly every solution of all the substances worked with at the various wave-lengths studied. It was found that the readings for the different solutions of the same substance having the same concentration were, for a given wave-length, different from one another to the extent of somewhat less than 2 per cent. From this it seems fair to assume that the error in our work was not greater than 2 per cent.

An examination of the tables of data for potassium chloride, ammonium chloride, and ammonium nitrate,—that is, for those substances which, in aqueous solutions, combine with very little water, as was demonstrated by the freezing-point method,—shows that for all wave-lengths studied the solution, and water of the same depth as the water in the solution have practically the same transmission. The dissolved substance does not combine with the solvent water, and the water in the solution has almost exactly the same effect upon light as so much pure water would have. This is exactly what would be expected from our knowledge of the absorption of light by dissolved substances and by the solvent. When we began this work, we supposed that the water in the solution, whether it was combined with the dissolved substance or not, would have the same power to absorb light as so much pure solvent water. We shall now see that such is not the case.

The results for the above-named substances were not plotted in the form of curves, since the curve for water and for the solution would practically coincide with one another; the dissolved substance having very little absorption over the region of wavelengths studied in this investigation.

When we turn to the data in Tables III and IV, very different relations manifest themselves. These are the data for calcium chloride, magnesium chloride, and aluminium sulphate,—that is, for salts which, in aqueous solution, are strongly hydrated, as was shown by the earlier work in this laboratory.[60] The solution in these cases is often more transparent than the same amount of water that is contained in the solution.

FIG. 15.



That these relations may appear the more clearly, the results obtained for the above-named salts are plotted as curves in Figs. 15 to 20. Fig. 15 is the curve for calcium chloride having a depth of 20 mm. This was obtained by dividing the deflection produced by 21 mm. of the solution by that produced by 1 mm. of the solution. On the same sheet we have the curve for water having a depth equal to that of the water in the calcium chloride. This curve for water was also obtained by the "differential" method,—*i.e.*, by dividing the deflections produced by the deeper solution by those obtained with the more shallow solution; the difference in the depths of water in the two cases being just equal

[60] Carnegie Institution of Washington, Publication No. 60.

to the depth of water in 20 mm. of the solution in question. Fig. 16 is the curve for calcium chloride with a depth of layer of 10 mm. (11 – 1). The data from which the curve was plotted are contained in Table IV. The smaller depth of solution was used so that the water-band between 1.2μ and 1.3μ would come out more distinctly. The results for this solution, like those for all the others, are compared with the absorption of a depth of water equal to that of the water in the solution. The absorption of the water in this, as in all other cases, was obtained by the "differential" method.

Fig. 17 is the curve for magnesium chloride having a depth of 21 – 1 = 20 mm. and the corresponding water curve. The data from which these curves are plotted are given in Table III.

FIG. 16.

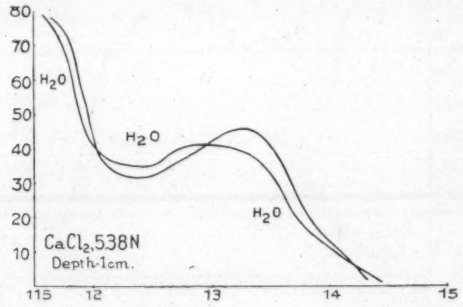


Fig. 18 is the curve for magnesium chloride having a depth of 1 cm., also obtained by the "differential" method. These data are taken from Table IV.

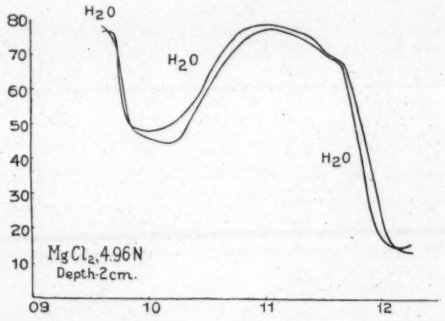
Fig. 19 is the curve for aluminium sulphate having a depth of 21 – 1 = 20 mm. and the corresponding absorption curve for water.

Fig. 20 is the curve for aluminium sulphate having a depth of 11 – 1 = 10 mm. and the corresponding water curve.

Fig. 15 shows the relative absorption of water and of the solution of calcium chloride having a concentration of 5.3 normal and a depth of 20 mm. The corresponding water curve is marked throughout by the symbol "H_2O." The solution is the more

transparent from 0.9μ to nearly 1μ. The water then becomes the more transparent over a short region of wave-lengths. From 1.05μ to 1.2μ the solution is the more transparent. In this region the solution becomes as much as 25 per cent. more transparent than the pure water, as can be seen by comparing the points on the "water" curve with the corresponding points on the curve for the solutions which are vertically above the points on the water curve. The water becomes appreciably more transparent only at and near the bottom of the "water-band" having a wave-length of approximately 1μ. This is the effect that we would expect to get if the dissolved substance exerted a "damping" effect on the absorption of light by water.

FIG. 17.



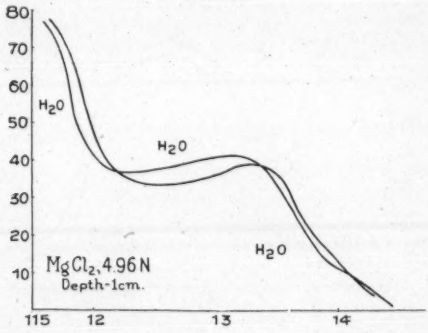
It will be recalled that the salts which do not form hydrates show, in aqueous solution, practically the same absorption as the corresponding amount of water. It would, therefore, seem reasonable to account for the differences in the case of non-hydrating and strongly hydrating salts, as due to the water of hydration, or the water that, in this case, is combined with the calcium chloride.

The curves in Fig. 16 are for a smaller depth of the same solution of calcium chloride. This figure brings out the same general relations as were shown in Fig. 15. The water curve in the region 1.25μ is above that of the solution, showing that water in this region for the more shallow depth of solution is

more transparent than the solution. The additional feature brought out by this figure is the water-band in the region 1.4μ to 1.5μ. After the first-named water-band is passed the solution becomes more transparent than the water, and remains so until the wave-length 1.42μ is reached. Here both the solution and the water are practically opaque, as is shown by both the curves approaching the abscissæ.

The curve for magnesium chloride having a depth of 20 mm. is almost exactly a duplicate of that for calcium chloride having the same depth. Practieally the only difference worthy of mention is in the region from 1.0μ to 1.1μ. In the case of magnesium chloride the water remains the more transparent over this region

FIG. 18.



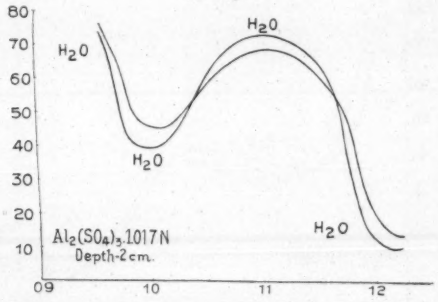
of wave-lengths. In the case of calcium chloride the solution is the more transparent over this region. The difference in the transparency of the water and the solution throughout the region is, however, not very great. From 1.1μ toward the longer wave-lengths, as we come down the descending arm of the curve towards the second water-band, the water in the case of the magnesium chloride, as in the case of calcium chloride, becomes much more transparent than the solution; the differences here being of the same order of magnitude as those with calcium chloride.

Fig. 18 gives the results for magnesium chloride with a depth of layer of 1 cm. The same relations hold in Fig. 18 as in Fig. 17, for the relative transparency of the water and of the solution.

The water becomes the more transparent from 1.22μ to 1.34μ. For the longer wave-lengths the solution becomes more transparent until the region 1.41μ is passed. For wave-lengths longer than 1.41μ, the transmission of both solution and water is practically zero,—that is, they both become opaque to the longer wave-lengths.

The results in Fig. 19 bring out some new features of interest and importance. These are the results that were obtained with aluminium sulphate. The new feature shown by the curve for aluminium sulphate, as compared with those for calcium chloride and magnesium chloride, is that at the minimum of the curve corresponding to wave-length 1μ, the solution is more transparent

FIG. 19.



than the corresponding water. Beyond the wave-length 1.04μ, the water becomes the more transparent with aluminium sulphate as with magnesium chloride. Beyond the wave-length 1.06μ, the solution becomes more transparent in this case as with magnesium chloride and calcium chloride.

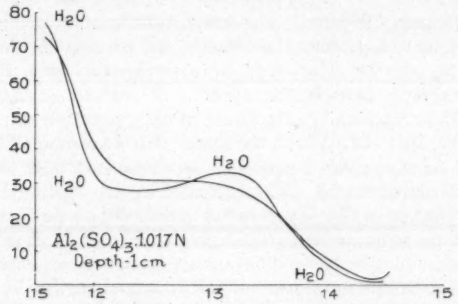
If we turn to Fig. 20 the relations are as follows: In the region of 1.2μ the water is the more opaque. From 1.209μ to 1.306μ the water becomes the more transparent. From 1.306μ to the longest wave-length studied, the solution again becomes more transparent than the corresponding layer of water.

An examination of all the results thus far obtained, bearing on this problem, leads us to conclude that the greater transparency of the solution as compared with the water in the solution, must

be due to some action of the dissolved substance on the solvent water. The question remains, What is this action?

We have seen from our earlier work on the absorption spectra of solutions, which has been in progress in this laboratory continuously for the past eight years, that the solvent can have a marked effect on the power of the dissolved substance to absorb light. This was first shown by Jones and Anderson,[61] and a large number of examples of this effect have since been found by Jones and Strong.[62] We interpreted the effect of the solvent on the power of the dissolved substance to absorb light, as due to a combination between a part of the liquid present and the dissolved substance. This enabled us to explain a large number

FIG. 20.



of facts that were brought to light for the first time by the investigations of the absorption spectra of solutions which have been carried on in this laboratory. Many of the phenomena which were thus explained, it seemed, could not be explained in terms of any other suggestion that has thus far been made. In a word, the solvate theory of solution, as proposed by Jones about fourteen years ago,[63] to supplement the theory of electrolytic dissociation in order that we might have a theory of the real solutions that we use in the laboratory, and not simply a theory of ideal

[61] Carnegie Institution of Washington, Publication No. 110.
[62] *Ibid.*, Nos. 130 and 160.
[63] *Amer. Chem. Journ.*, 23, 103 (1900).

solutions as the theory of electrolytic dissociation alone must be regarded, has served good purpose in explaining the phenomena that have been previously observed in connection with the absorption of light by solutions of dissolved substances.

We are inclined to explain the phenomena recorded in this paper by means of the same theory. For solutions of those substances which have been shown by entirely different methods not to hydrate to any appreciable extent, the absorption of light by the solution, and by a layer of water equal in depth to that of the water in the solution, is, to within almost the limit of experimental error, the same.

For those substances, however, which have been shown to form complex hydrates, the absorption of light by their solutions, and by a layer of water equal in depth to that of the water in the solution, is very different. The water in these solutions is usually more opaque to light than the solution, or, what is the same thing in other words, the solution is more transparent than the water that is present in the solution.

The most rational explanation of this phenomenon appears to us to be, that the part of the water that is combined with the dissolved substance, has a smaller power to absorb light than pure, free, uncombined water. The fact that we are able to detect the difference between the water in the solution and pure water, by its action on light, we regard as good evidence in favor of the water in the solution being different from pure, free water. This difference, it seems to us, can be readily accounted for by the fact that a part of the water present in the solution is in combination with the dissolved substance.

We have carried out similar investigations with aluminium nitrate, but the concentration of the strongest solution that could be obtained was not sufficiently great to show the phenomenon in question. We, therefore, do not incorporate the results obtained with this substance. That the solutions must be very concentrated to show clearly the phenomenon with which we are dealing, is shown by the results given in Table V. Here the solutions of the three salts in question that were used, are more dilute than those for which the results are tabulated in Tables III and IV. An examination of this table will show that the phenomenon in question does not manifest itself to anything like the same extent as with the more concentrated solutions. This is exactly

what we would expect in terms of the solvate theory of solutions. The more concentrated the solution, the larger the total amount of the water present combined with the dissolved substance. If combination between water and the dissolved substance explains the facts recorded in this paper, then the larger the amount of water present that is combined with the dissolved substance, the more pronounced the phenomenon in question.

The results obtained with aluminium sulphate bring out the same facts shown by calcium chloride and magnesium chloride. They, however, show in addition, that water is more transparent in the region of 1.1μ and more opaque at 1μ. That the sulphate should not agree throughout with the chlorides is really not surprising, since the sulphates show abnormal results in almost every particular. This is probably due, in part at least, to the large amount of polymerization which the sulphate molecules in general undergo in the presence of even water as a solvent. It should also be remembered in the present connection, that, while calcium chloride and magnesium chloride crystallize with only six molecules of water, and are, therefore, only largely hydrated, aluminium sulphate crystallizes with 18 molecules of water and is, therefore, very largely hydrated.

The results in Table VI are, as has already been stated, the radiomicrometer deflections for a solution of aluminium sulphate, and those for water having the same depth as the water in the solution in question, and the corresponding data for potassium chloride. A comparison of the two columns for potassium chloride and its corresponding water, shows that the two are almost equally transparent to all the wave-lengths studied.

A comparison of aluminium sulphate with its corresponding water, brings out the phenomenon that we are now discussing in a very pronounced manner. It is for this reason that the data in this paper are given.

One other relation of a general character should be pointed out. The curves upon all six of the figures show that the addition of salt to water shifts the absorption towards the longer wave-lengths. This is analogous to what has already been found by Jones and Uhler,[64] Jones and Anderson,[65] Jones and Strong,[66]

[64] Carnegie Institution of Washington, Publication No. 60.
[65] *Ibid.*, Publication No. 110.
[66] *Ibid.*, Publications Nos. 130 and 160.

and Guy and Jones,[67] when the absorption of salts as affected by the water present was studied. It was found that rise in temperature and increase in the concentration of the solution both tended to shift the absorption of the salt towards the longer wave-lengths. The effect of rise in temperature and increase in the concentration of the solution tended to simplify the hydrates in combination with the particles of the salt. The resonator within this simplified system seems to vibrate so as to shift the absorption bands towards the red.

The effect of the salt on the absorption of the water, is the same as that of rise of temperature and increase of concentration on the absorption of the dissolved substance. We should naturally look for a similar explanation of the two sets of phenomena. It has been suggested by Dr. Guy that the effect of the salt on the absorption of light by water may be due to the breaking down of the associated molecules of water by the dissolved substance. This would be in keeping with the discovery made by Jones and Murray,[68] that one associated substance when dissolved in another associated substance diminishes its association.

In terms of this explanation, however, it is a little difficult to see why non-hydrated salts, such as were used in this work, do not also diminish the association of water and cause a shifting of its absorption bands towards the longer wave-lengths. It may be that the effect of the dissolved substance in breaking down the association of the water, is pronounced only in the case of water of hydration, or the water that is combined with the dissolved substance, and that the explanation offered above is fundamentally correct.

We wish to express our thanks to Prof. A. H. Pfund, who has made many valuable suggestions during the progress of this phase of the work. We would also express our thanks to Dr. E. P. Wightman, who has kindly drawn the curves for us, and to Dr. E. J. Shaeffer, who has assisted in preparing the solutions, and in making the readings.

SUMMARY AND DISCUSSION.

The following twelve independent lines of evidence bearing upon the solvate theory of solution have, then, been established:

[67] Carnegie Institution of Washington, Publication No. 190, *Amer. Chem. Journ.*, 49, 1 (1913).

[68] *Amer. Chem. Journ.*, 30, 193 (1903).

1. Relation between water of crystallization and lowering of the freezing-point of water.

2. Relation between water of crystallization and temperature of crystallization.

3. Minima in the boiling-point curves.

4. Hydrating power and temperature coefficients of conductivity.

5. Dissociation as measured by the freezing-point method, and by the conductivity method.

6. Hydrating power of the ions and their velocities.

7. Action of a salt with hydrating power on another salt in the same solution.

8. Work in mixed solvents.

9. Evidence for solvation based upon the power of solutions to absorb light. Work of Jones and Uhler, on the effect of concentration, dehydrating agents, etc.

10. Work of Jones and Anderson on absorption spectra, in which the presence of " solvate " bands was first detected. This showed that the solvate had an effect on the absorption of light, and this could be explained only as due to a combination between the solvent and the resonator, or something containing the resonator.

11. The work of Jones and Strong on absorption spectra established the existence of a larger number of " solvent " bands. They showed that these were formed by many salts, and in many solvents. They could even distinguish between the bands of a salt in a given alcohol and in its isomer. This was regarded as very important. The temperature work of Jones and Strong was also in keeping with the solvate theory.

12. The work of Jones and Guy on the effect of high temperature on the absorption spectra of aqueous solutions, and also on the effect of dilution, led to results which were all in keeping with the solvate theory.

The most important spectroscopic work of Jones and Guy, as bearing on the solvate theory of solution, is that in which the radiomicrometer was used. It was here shown that solutions of certain strongly-hydrated non-absorbing salts, are *more transparent* than pure water having a depth equal to that of the water in the solution. In the case of non-hydrated salts the solution

was the more opaque. This shows that water in combination with the dissolved substance—water of hydration—has less absorption than pure, free water. This is regarded as striking evidence that some of the water in the presence of salts which are shown by other methods to hydrate, is different from pure, free, uncombined water; and the simplest explanation seems to be that this is the combined water, or the water of hydration.

The above twelve *independent lines of evidence* all point to the general correctness of the view that when a salt is dissolved in a solvent, there is more or less combination between the salt, or the ions resulting from it, and the solvent. The magnitude of this solvation depends upon the nature of the substance and of the solvent.

The question then arises, Of what significance or scientific value is the establishing of the fact that there is more or less combination between the dissolved substance and the solvent? This has already been discussed in various connections.[69]

SIGNIFICANCE OF THE SOLVATE THEORY OF SOLUTION.

The evidence for the solvate theory of solution which has been furnished in this laboratory as the result of somewhat more than a dozen years of investigation, has recently been brought together and briefly discussed.[70] The evidence is so unambiguous and convincing, that ions and some molecules combine with more or less of the solvent, that it seems that it can now be accepted as a fact of science.

This, however, raises a number of questions: What relation does the solvate theory of solution bear to the theory of electrolytic dissociation?

Does the solvate theory help us to explain any of the apparent discrepancies in the theory of electrolytic dissociation? Does the solvate theory help us to explain the facts of chemistry in general and of physical chemistry in particular? Why is the nature of solution so important, not only for chemistry but for science in general?

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[69] See especially my little book "A New Era in Chemistry," just published by the D. Von Nostrand Co.

[70] *Z. physik. Chem.*, 74, 325 (1910).

The Solvate Theory and the Theory of Electrolytic Dissociation.

When Arrhenius proposed the theory of electrolytic dissociation, the question was not even raised as to the condition of the ions in the solution, except that they behave as if they existed independently of one another in solution. The theory simply said that molecules of acids, bases, and salts in the presence of a dissociating solvent like water, break down to a greater or less extent into charged parts called ions; the cations or positively charged parts being electrically equivalent to the anions or negatively charged parts. The cations are usually simple metallic atoms carrying one or more unit charges of positive electricity. The cation might, however, be more or less complex, as illustrated by ammonium and its substitution products. The anion is usually complex, consisting of a larger or smaller number of atoms. It may, however, be an atom carrying negative electricity, as in the case of the halogen acids and their salts.

The degree of dissociation is determined by the nature of the acid, base, or salt. Strong acids and bases are greatly dissociated. Indeed, the degree of dissociation determines their strength. Nearly all of the salts are strongly dissociated compounds; there being, however, some exceptions; as, notably, the halogen salts of mercury, cadmium, and zinc. There are, however, considerable differences in the amounts to which salts in general are dissociated at the same dilution.

The quantitative evidence furnished by Arrhenius and others for the theory of electrolytic dissociation, is so convincing that few chemists of any prominence, who have carefully examined the evidence, have ever doubted the general validity of the theory; and the theory has become substantiated by such an abundance of subsequently discovered facts, that it has now become a law of nature and a fundamental law of chemical science.

Arrhenius saw and pointed out clearly the importance of ions for chemistry; and Ostwald and his pupils have shown that chemistry is essentially a science of the *ion;* molecules for the most part being incapable of reacting chemically with molecules; and Nernst has shown that the ion is the active agent in all forms of primary cells.

The theory of electrolytic dissociation, as already stated, does not raise the question as to the relation between the ion and

the solvent. At the time that the theory was proposed, chemists did not know, and probably had no means of finding out, whether the ion is or is not combined with the solvent in contact with it. The solution of this problem remained for subsequent work.

Some of the many lines of evidence that ions and certain molecules are combined with a larger or smaller number of molecules of the solvent, and in many cases with a very large number of molecules of the solvent, have been recently discussed briefly by Jones in an article in the *Zeitschrift für physikalische Chemie*.[71]

The amount of the solvent combined with an ion is primarily a function of the nature of the ion or ions in the solution. It is, however, conditioned very largely by the dilution of the solution, and also by the temperature.

The evidence, some of which is given in the paper referred to above, and the remainder in other publications of the results of investigations carried out in this laboratory during the past fourteen years, shows that the power of the ions to combine with the solvent is by no means limited to water and aqueous solutions, but is a property of solutions in general. The alcohols, acetone, glycerol,[72] etc., combine with certain substances dissolved in them; and it seems more than probable that all solvents combine with the dissolved substances to a greater or less extent. In a word, we do not have simply a theory of hydration, but a theory of solvation in general; which is an essential part of any generalization that would take into account the facts presented by solution.

The solvate theory of solution has been regarded in some quarters as a rival of the electrolytic dissociation theory of solution; if not directly antagonistic to it. Such is not at all the case. The solvate theory begins where the theory of electrolytic dissociation ends. The latter gives us the ions from molecules, and the former tells us what is the condition of the ions in the presence of a solvent after they are formed.

The solvate theory of solution, then, simply supplements the theory of electrolytic dissociation, and both must be taken into account if we ever wish to understand the phenomena presented by solution.

[71] "Evidence Obtained in this Laboratory during the Past Twelve Years for the Solvate Theory of Solution." *Z. physik. Chem.*, 74, 325 (1910).

[72] "Conductivity and Viscosity in Mixed Solvents," by H. C. Jones and Coworkers, Carnegie Institution of Washington, Publication Nos. 80 and 180.

Does the Solvate Theory Help to Explain Any of the Apparent Exceptions to the Theory of Electrolytic Dissociation?

Given the theory of solvation in solution, together with that of electrolytic dissociation, the first question that arises is, Does the former really aid us in explaining the phenomena presented by solutions?

Shortly after the theory of electrolytic dissociation was proposed, it was recognized, and repeatedly pointed out, that after all it is only a theory of "ideal solutions,"—*i.e.*, very dilute solutions. It was shown not to be able to explain many of the phenomena presented by even fairly concentrated solutions. Indeed, it frequently could not deal quantitatively with the very solutions with which we work in the laboratory.

The explanation of this shortcoming was not fully seen, and an analogy was resorted to. It was pointed out that the laws of Boyle and Gay-Lussac for gases hold only for "ideal gases,"—*i.e.*, dilute gases,—but do not hold for gases of any considerable concentration.

It was stated that the gas laws when applied to solutions could not be expected to hold more generally than when applied to gases, and there the matter was allowed to rest.

In the early days of the theory of electrolytic dissociation, it was, however, pointed out, that we have a fairly satisfactory explanation of why the simple gas laws do not hold for concentrated gases; this being expressed in the equation of Van der Waals; while no analogous explanation was offered in the case of solutions.

That this point was well taken is obvious. A theory of solution to be of the greatest value must be applicable to all solutions; regardless of the nature of the substance; regardless of the nature of the solvent; and regardless of the concentration of the solution.

The explanation of these apparent exceptions to the theory of electrolytic dissociation presented by concentrated solutions has been furnished by the solvate theory. We now know that, for solutions in general, a part of the solvent is combined with the dissolved substance. While the amount of the solvent combined with any one ion is greater the more dilute the solution, at least up to a certain point, the total amount of the solvent in combina-

tion with the dissolved substance is greater the more concentrated the solution.

That the amount of combined solvent may become very great, even relative to the total amount of solvent present, can be seen from the following facts: In a normal solution of calcium chloride about two-fifths of the total water present is combined with the dissolved substance. In a three-normal solution of calcium chloride about five-sevenths of the total water is combined.

In the case of a normal solution of aluminium chloride in water, about five-eighths of the water present is combined with the dissolved substance, while in a two-normal solution about five-sixths of the water present is in a state of combination.[73]

What we suppose to be a normal solution of calcium chloride is, therefore, more than one and one-half times normal; while what we suppose to be a three-normal solution is in reality more than eight times normal. In the case of aluminium chloride, what we suppose to be a normal solution is more than twice normal, while what we prepare as a twice normal solution is about twelve times normal.

These few facts, taken from thousands of a similar character, show that even fairly concentrated solutions are much more concentrated than we would suppose from the method of their preparation; while very concentrated solutions are many times more concentrated than, without the facts of solvation, we should be led to think.

The general conclusion is that even fairly concentrated solutions are much stronger than if no solvation occurred; and are much more concentrated than we are accustomed to consider from the amount of substance added to a given volume of the solution—more or less of the water present being in combination and only the remainder playing the rôle of solvent. Without the theory of solvation, we have hitherto regarded all the water present as acting as solvent.

We should, therefore, not expect the laws of gases to apply to such solutions, when we had no idea what was their concentration. Now that we know their concentration, we find that the laws of gases are of as general applicability to solutions as to

[73] "Hydrates in Aqueous Solution," by H. C. Jones and Coworkers, Carnegie Institution of Washington, Publication No. 60.

gases, holding not simply for dilute, but also for concentrated solutions.

The theory of electrolytic dissociation, supplemented by the theory of solvation, is, then, not simply a theory of dilute or "ideal" solutions, but a theory of solutions in general.

Does the Solvate Theory Aid Us in Explaining the Facts of Chemistry in General and of Physical Chemistry in Particular?

To answer this question at all fully would lead us far beyond the scope of this paper. A few facts bearing upon this question can, however, be taken up. Take, for example, the action of the hydrogen ion both in the formation and the saponification of esters. In the presence of the alcohols the hydrogen accelerates greatly the velocity with which an ester is formed; while in the presence of water it causes the ester to break down into the corresponding acid and alcohol.

In terms of ordinary chemical conceptions it is difficult, not to say impossible, to interpret these reactions—the hydrogen ion under one set of conditions undoing what under other conditions it effected.

In terms of the solvation theory these reactions admit of a very simple interpretation. While the hydrogen ion is not strongly solvated, yet work in this laboratory has shown that all ions are more or less solvated. In the presence of alcohol the hydrogen ion therefore combines with a certain amount of this solvent. The hydrogen ion, plus the alcohol combined with it, unites with the organic acid, forming complex alcoholated ions, which then break down, forming the ester.

On the other hand, the hydrogen ion in the presence of water combines with a certain amount of this solvent. The hydrated hydrogen ion, together with the water united with it, combines with the ester, forming a complex hydrated ion, which then breaks down into the corresponding acid and alcohol, setting the hydrogen ion free again.

For a fuller discussion of this reaction see the paper by E. Emmet Reid.[74]

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[74] *Amer. Chem. Journ.*, 41, 504 (1909).

A reaction analogous to the above is that of hydrogen ions on amides in the presence of water, on the one hand, and of alcohol on the other. In the presence of water the hydrated hydrogen ion combines with the amide, forming a complex hydrated ion which then breaks down, yielding ammonia and acid, the ammonia, of course, combining with the acid.

In the presence of alcohol the alcoholated hydrogen ion combines with the amide, forming a complex alcoholated ion, which then breaks down into ammonia and the ester of the acid in question.

Hydrogen ions in a mixture of water and alcohol, which would contain both hydrated and alcoholated hydrogen ions, give both reactions simultaneously; but, as Reid has pointed out, in the presence of an equal number of molecules of water and alcohol, the tendency of the hydrogen ion to hydrate is greater than the tendency to form alcoholates; and under these conditions the first reaction proceeds much more rapidly than the second.[75]

A very large number of types of reactions could be discussed illustrating this same point,—*i.e.*, the value of the solvate theory in interpreting chemical reactions.

When we turn to physical chemical processes, the solvation of the ions has to be taken into account at every turn. The velocities of the ions are, of course, a function of the degree of their solvation; and the behavior of the ions, both chemically and physically, is a function of their velocities. The effect of dilution, and especially of temperature on reaction velocities, is largely a question of the velocities of the ions present, which, in turn, are a function of the degree of their solvation.

In determining the actual concentration of a solution, the amount of the solvent combined with the ions must be taken into account, as has already been pointed out; and without knowing the actual concentrations of solutions quantitative chemistry would be impossible.

The solvate theory has thrown a flood of light on the whole subject of the conductivity of solutions, or the power of the ions to carry the electric current. It has shown us why the conductivity of lithium salts is less than that of sodium and potassium; notwithstanding the fact that the lithium ion is much smaller

[75] *Amer. Chem. Journ.*, 41, 509 (1909).

and lighter than the atom of sodium and potassium. We now know that the lithium ion is much more hydrated than the ions of sodium and potassium, and the mass of the moving ion is really much greater than that of sodium or potassium.

When we come to the temperature coefficients of conductivity, the solvate theory has enabled us to interpret results which, without its aid, would be meaningless. We now know why ions with the greater hydrating power have the larger temperature coefficients of conductivity. We know why ions with the same hydrating power have approximately the same temperature coefficients of conductivity; and why dilute solutions have larger temperature coefficients of conductivity than concentrated solutions;[76] and we could multiply examples almost without limit, did space permit, of the effect of the solvate theory on physical or general chemistry.

Why is the Nature of Solutions of such Vital Importance not only for Chemistry but for Science in General?

The fact is well recognized that modern physical or general chemistry has reached out into nearly every branch of science, and has had an important influence on many of them. The question arises: Why is this the case? The answer is that physical or general chemistry is primarily a science of solutions.

This answer may not at first sight appear to be self-evident, but a moment's thought will show its general correctness. The whole science of chemistry is primarily a science of solutions in the broad sense of that term. By solutions is meant not simply solutions in liquids as the solvent; but solutions in gases and in solids as well; and not simply solutions at ordinary temperatures, but also at elevated temperatures. If we think of chemical reactions in general, we will realize what a small percentage of them take place out of solution. Therefore, the nature of solution is absolutely fundamental for chemistry. This applies not simply to general chemistry, including the chemistry of carbon; but also to physiological chemistry, which deals almost entirely with solutions in one solvent or another.

When we turn to physics we find solutions not playing as prominent a rôle as in chemistry, but nevertheless coming in in

[76] Jones, *Amer. Chem. Journ.*, 35, 445 (1906).

many places. The primary cells, secondary cells, electrolysis, polarization, diffusion, viscosity, surface-tension, are all phenomena in which the physicist is interested, and all depend for their existence upon solution.

When we turn to the biological sciences we find that solution is almost as important as for chemistry. Take animal physiology; here we have to deal very largely with solution in the broad sense of that term. The same remark applies to physiological botany; and solutions are very important for both animal and vegetable morphology, especially in their experimental developments. Bacteriology is fundamentally connected with solutions, and pharmacology is based upon solutions either without or within the body of the animal.

Solution in the broad sense is as fundamental for geology as for chemistry. The igneous rocks were solutions of one molten mass in another, and sedimentary deposits came down for the most part from solutions in water. The minerals crystallized out from solutions, and solutions of various substances, such as carbon dioxide, are to-day weathering the rocks and continually changing the appearance of the face of the globe.

An examination of facts such as those referred to above, will show the truth of the statement that the relation of physical or general chemistry to solutions, is the prime reason why physical or general chemistry is so closely related to so many other branches of natural science.

This alone would show the importance of a true and comprehensive theory of solutions, not alone for physical or general chemistry, but for the natural sciences in general.

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15. Jones and McMaster: "On the Formation of Alcoholates by Certain Salts in Solution in Methyl and Ethyl Alcohols." *Amer. Chem. Journ.*, **35**, 316 (1906).

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17. Jones and Uhler: "The Absorption Spectra of Certain Salts in Aqueous Solution as Affected by the Presence of Certain Other Salts with Large Hydrating Power." *Amer. Chem. Journ.*, **37**, 126 (1907).

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26. Jones and Strong: "The Absorption Spectra of Various Salts in Solution, and the Effect of Temperature on Such Spectra." *Amer. Chem. Journ.*, **43**, 37 (1910).

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38. Jones and Guy: "Die Absorptionsspektren wässeriger Lösungen von Neodym- und Praseodymsalzen, mit dem Radiomikrometer gemessen." *Phys. Zeit.*, **13**, 649 (1912).

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CONDUCTIVITY, TEMPERATURE COEFFICIENTS OF CONDUCTIVITY AND DISSOCIATION IN AQUEOUS SOLUTIONS.

41. Jones and West: "A Study of the Temperature Coefficients of Conductivity in Aqueous Solutions, and on the Effect of Temperature on Dissociation." *Amer. Chem. Journ.*, **34**, 357 (1905).

42. Jones and Jacobson: See above, No. 22.

43. Jones and White: "The Effect of Temperature and Dilution on the Conductivity of Organic Acids in Aqueous Solution." *Amer. Chem. Journ.*, **42**, 520 (1909).

44. Clover and Jones: "The Conductivities, Dissociations, and Temperature Coefficients of Conductivity between 35° and 80° of Solutions of a Number of Salts and Organic Acids." *Amer. Chem. Journ.*, **43**, 187 (1910).

45. White and Jones: "The Conductivity and Dissociation of Organic Acids in Aqueous Solution at Different Temperatures." *Amer. Chem. Journ.*, **44**, 159 (1910).

46. West and Jones: "The Conductivity, Dissociation, and Temperature Coefficients of Conductivity at 35°, 50°, and 65° of Aqueous Solutions of a Number of Salts." *Amer. Chem. Journ.*, **44**, 508 (1910).

47. Wightman and Jones: "A Study of the Conductivity and Dissociation of Organic Acids in Aqueous Solution between Zero and Thirty-five Degrees." *Amer. Chem. Journ.*, **46**, 56 (1911).

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49. Winston and Jones: "The Conductivity, Temperature Coefficients of Conductivity, and Dissociation of Certain Electrolytes in Aqueous Solution

from 0° to 35°. Probable Inductive Action in Solution, and Evidence for the Complexity of the Ion." *Amer. Chem. Journ.*, 46, 368 (1911).

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51. Springer and Jones: "A Study of the Conductivity and Dissociation of Certain Organic Acids in Aqueous Solution at Different Temperatures." *Amer. Chem. Journ.*, 48, 411 (1912).

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54. Smith and Jones: "Conductivity, Temperature Coefficients of Conductivity, Dissociation, and Dissociation Constants of Certain Organic Acids between 0° and 65°." *Amer. Chem. Journ.*, 50, 1 (1913).

55. Jones: "The Bearing of Hydrates on the Temperature Coefficients of Conductivity of Aqueous Solutions." *Amer. Chem. Journ.*, 35, 445 (1906).

WORK IN MIXED SOLVENTS.

56. Jones and Lindsay: "A Study of the Conductivity of Certain Salts in Water, Methyl, Ethyl, and Propyl Alcohols, and in Mixtures of These Solvents." *Amer. Chem. Journ.*, 28, 329 (1902).

57. Jones and Murray: "The Association of a Liquid Diminished by the Presence of Another Associated Liquid." *Amer. Chem. Journ.*, 30, 193 (1903).

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59. Jones and Carroll: "A Study of the Conductivities of Certain Electrolytes in Water, Methyl and Ethyl Alcohols, and Mixtures of These Solvents. Relation between Conductivity and Viscosity." *Amer. Chem. Journ.*, 32, 521 (1904).

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65. Jones and Veazey: "A Possible Explanation of the Increase in Viscosity which Results When the Alcohols are Mixed with Water; and of the Negative Viscosity Coefficient of Certain Salts When Dissolved in Water." *Amer. Chem. Journ.*, **37**, 405 (1907).

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70. Jones and Mahin: "Conductivity and Viscosity of Dilute Solutions of Lithium Nitrate, and Cadmium Iodide in Binary and Ternary Mixtures of Acetone with Methyl Alcohol, Ethyl Alcohol, and Water." *Zeit. phys. Chem.*, **69**, 389 (1909).

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72. Guy and Jones: "Conductivity and Viscosity in Mixed Solvents Containing Glycerol." *Amer. Chem. Journ.*, **46**, 131 (1911).

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76. Davis, Hughes and Jones: "Conductivity and Viscosity of Solutions of Rubidium Salts in Mixtures of Acetone and Water." *Zeit. phys. Chem.*, 1913.

MONOGRAPHS

on researches dealing directly or indirectly with the subject in hand, published by the Carnegie Institution of Washington:

1. HYDRATES IN AQUEOUS SOLUTION. Evidence for the Existence of Hydrates in Solution, Their Approximate Composition, and Certain

Spectroscopic Investigations Bearing Upon the Hydrate Problem. By Harry C. Jones, with the assistance of F. H. Getman, H. P. Bassett, L. McMaster, and H. S. Uhler. Carnegie Institution of Washington, Publication No. 60 (1907).

2. CONDUCTIVITY AND VISCOSITY IN MIXED SOLVENTS. A Study of the Conductivity and Viscosity of Certain Electrolytes in Water, Methyl Alcohol, Ethyl Alcohol, and Acetone; and in Binary Mixtures of These Solvents. By Harry C. Jones and C. F. Lindsay, C. G. Carroll, H. P. Bassett, E. C. Bingham, C. A. Rouiller, L. McMaster, and W. R. Veazey. Carnegie Institution of Washington, Publication No. 80 (1907).

3. THE ABSORPTION SPECTRA OF SOLUTIONS of Certain Salts of Cobalt, Nickel, Copper, Iron, Chromium, Neodymium, Praseodymium, and Erbium in Water, Methyl Alcohol, Ethyl Alcohol, and Acetone, and in Mixtures of Water with the Other Solvents. By Harry C. Jones and John A. Anderson. Carnegie Institution of Washington, Publication No. 110 (1909).

4. A STUDY OF THE ABSORPTION SPECTRA of Solutions of Certain Salts of Potassium, Cobalt, Nickel, Copper, Chromium, Erbium, Praseodymium, Neodymium, and Uranium, as Affected by Chemical Agents and by Temperature. By Harry C. Jones and W. W. Strong. Carnegie Institution of Washington, Publication No. 130 (1910).

5. THE ABSORPTION SPECTRA OF SOLUTIONS OF COMPARATIVELY RARE SALTS, Including Those of Gadolinium, Dysprosium, and Samarium. The Spectrophotography of Certain Chemical Reactions, and the Effect of High Temperature on the Absorption Spectra of Non-aqueous Solutions. By Harry C. Jones and W. W. Strong. Carnegie Institution of Washington, Publication No. 160 (1911).

6. THE ELECTRICAL CONDUCTIVITY, DISSOCIATION AND TEMPERATURE COEFFICIENTS OF CONDUCTIVITY FROM ZERO TO SIXTY-FIVE DEGREES OF AQUEOUS SOLUTIONS OF A NUMBER OF SALTS AND ORGANIC ACIDS. By Harry C. Jones. The experimental work by A. M. Clover, H. M. Hosford, S. F. Howard, C. A. Jacobson, H. R. Kreider, E. J. Shaeffer, L. D. Smith, A. Springer, Jr., A. P. West, G. F. White, E. P. Wightman, and L. G. Winston. Carnegie Institution of Washington, Publication No. 170 (1912).

7. THE FREEZING-POINT, CONDUCTIVITY, AND VISCOSITY OF SOLUTIONS OF CERTAIN ELECTROLYTES IN WATER, METHYL ALCOHOL, ETHYL ALCOHOL, ACETONE, AND GLYCEROL, AND IN MIXTURES OF THESE SOLVENTS WITH ONE ANOTHER. By Harry C. Jones and Collaborators. (The seven collaborators in this monograph are Drs. C. M. Stine, J. N. Pearce, H. R. Kreider, E. G. Mahin, M. R. Schmidt, J. Sam Guy, and P. B. Davis.) Publication of the Carnegie Institution of Washington, No. 180 (1913).

8. THE ABSORPTION SPECTRA OF SOLUTIONS AS AFFECTED BY TEMPERATURE AND BY DILUTION. A QUANTITATIVE STUDY OF ABSORPTION SPECTRA BY MEANS OF THE RADIOMICROMETER. By Harry C. Jones and J. Sam Guy. Publication of the Carnegie Institution of Washington, No. 190 (1913).

JOHNS HOPKINS UNIVERSITY, BALTIMORE, September, 1913.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE Bureau is issuing a supplement to Circular No. 38, on the testing of rubber. At a conference of manufacturers and users of rubber insulation, held in New York, December 7, 1911, it was decided to take steps to improve and standardize methods for analyzing rubber compounds. In pursuance of the decision reached, a committee, now known as the Joint Rubber Insulation Committee, was appointed to devise specifications and an analytical procedure for rubber insulating compounds.

After the first report of this committee had been adopted unanimously by the conference, it was submitted to the Bureau of Standards, at the request of the committee, for tentative approval and possible publication. Because of actual participation by the Bureau in the work of the committee, and because of the importance of the report it is now published as a supplement to Circular No. 38, "The Testing of Mechanical Rubber Goods." It is believed that the report is a long step in the direction of standard specifications and suitable methods of analysis, the preparation of which is peculiarly germane to the work of the Bureau of Standards, and that it should prove of great value to consumer and manufacturer alike.

The Bureau of Standards is issuing a preliminary circular on "The Testing of Barometers." It is issued in advance of the final results of the Bureau's investigations only in response to repeated requests for information. It will serve to describe in a general way the testing of mercurial and aneroid barometers at the Bureau of Standards, and to announce the fees which are charged for the various tests.

CIRCULAR NO. 45, ON THE TESTING OF MATERIALS.

ANNOUNCEMENT was previously made of the issue of a circular on the testing of materials. The circular has now appeared and may be obtained upon application to the Bureau of Standards. The general importance in this subject makes it of interest to give a summary of the topics treated in this circular:

* Communicated by the Bureau.

I. Introduction.
   1. Purpose.
   2. Testing of Materials.
   3. Classes of Materials.
   4. Properties of Materials.
   5. Determination of Properties of Materials.
   6. The Measure of Quality.
   7. Specifications or Standards of Quality.
   8. Improvement of Specifications.

II. General Information Concerning the Testing of Materials.
   1. Choice of Tests.
   2. Sampling and Selection of Test Pieces.
   3. Application for Testing.
   4. Shipping Directions.
   5. Identification Marks.
   6. Time Required for Testing.
   7. Results of Tests and their Interpretation.
   8. Fees for Testing.
   9. For Whom Tests are Made.

III. Special Information Concerning the Classes of Materials Tested.
   1. Metals.
      A. Metals and metal products: Definition, sources and uses, purposes of tests. Nature of tests: Chemical analysis, metallographic examination and heat treatment. Mechanical tests: Tension, compression, flexure, torsion, hardness, strain measurements. Miscellaneous physical tests: Sampling and testing under specifications.
      B. Composite metal products: Plated and coated metals, enamels for cast iron and steel.
   2. Cements (hydraulic) and concrete.
      A. Portland cement: Definition, sources, uses. Properties of cement: Chemical tests. Physical tests: soundness, time of setting, tensile strength, fineness, specific gravity, and sampling.
      B. White cement.
      C. Natural cement.
      D. Raw cement materials.
      E. Sand and stone screenings.
   3. Ceramics.
      A. Clays and shales.
      B. Clay products: clay building brick, architectural terra cotta, roofing tiles, floor tiles, glazed wall tiles, paving blocks and bricks, sewer pipe, drain tiles, porcelain and white ware, fire clays, fire-proofing for steel protection, refractories.
   4. Lime.
      A. Burnt lime.
      B. Hydrated lime.

C. Raw materials for lime.
D. Sand lime brick.

5. Stone.
Description and properties, tests: Compression tests, freezing tests, absorption tests, transverse tests, sampling.

6. Paint materials.
A. Colorants: Oil colors, water colors, tinting colors, enamel paints, stains.
B. Oils: Linseed oil, driers, volatile thinners.
C. Varnishes: Spirit varnishes, oil varnishes.
D. Tests.
E. Sampling.

7. Bituminous materials.
Definition and classification, use and general requirements, tests and interpretation of results, general statement, sampling.

8. Inks.
A. Writing inks: Description, tests, sampling.
B. Printing inks.
C. Stamp pad inks: Drying power, fastness of color, sampling.

9. Paper.
Definition and sources, uses, quality, and sampling.

10. Textiles.
A. Fibres, yarns, and fabrics.
B. Manila rope.

11. Rubber.
Tests: (*a*) Physical tests, (*b*) Chemical tests, sampling: (*a*) Other conditions governing tests.

12. Leather.

13. Lubricating oils and greases.
A. Oils: Mechanical testing: (*a*) viscosity, (*b*) cold test, (*c*) flash and fire points. Chemical testing: (*a*) Mineral acid, (*b*) Soap, (*c*) Ash, (*d*) Asphalt test, (*e*) Organic acid, (*f*) Fat, (*g*) Carbonization, (*h*) Evaporation and gumming, (*i*) Specific gravity.
B. Greases.

14. Chemicals.

15. Miscellaneous technical materials.
A. Electrical and magnetic materials.
B. Optical materials.
C. Thermal materials.
D. Water for boiler and technical use.
E. Miscellaneous materials.
F. Standard analyzed samples.

16. Testing of instruments used for testing materials.

IV. Schedules of Fees.

V. Publications.

Aluminum as Flux. ROBERT GRIMSHAW. (*Metal Industry*, 11, 10, 425.)—Iron founders have long known that aluminum is an excellent flux. It oxidizes very easily and removes oxygen from the cast iron and steel, according to the formula $Al_2 + O_3 = Al_2O_3$, evolving 391,000 calories, an amount of heat sufficient to raise the temperature of one kilogramme of iron 1400° C., or one pound 5544° F. This heat causes the sudden foaming of the mass. The energetic movement noticed in the pouring ladle brings the molecules in contact with air, which produces iron oxide; but this oxidation can be avoided by covering the melted iron or steel mass with sand or charcoal. If the melted metal does not attain a high temperature the effect of the addition of aluminum is almost *nil*. The amount of fluxing metal necessary depends on the quality of steel and the purpose of the casting. For steel with 0.5 per cent. carbon there should be added from 160 to 320 grains of aluminum per ton, while for a higher carbon steel only 150 to 250 grains are necessary.

Granacite. H. FISHER. (*Zeit. Angew. Chem.*, xxv, 1327.)—Granacite, a form of granite found in Saxony, is especially suitable for towers, vessels, containers, etc., in the industrial manufacture of acetic acid and white lead, phosphoric acid, bromine, and alkali manufacture, and in the paper industry for sulphite liquors.

Action of Light on Coloring Matters. W. HARRISON. (*J. Soc. Dyers and Col.*, xxviii, 225.)—Experiments are quoted to show that: (1) Light from the mercury arc lamp does not act relatively the same as sunlight on all colors. (2) A mercury light of high intensity does not act relatively the same as one of low intensity. (3) Cellulose is decomposed by the action of light and air, with formation of reducing substances. (4) In a vacuum under the influence of light from a mercury lamp, cellulose acts as a reducing agent, but in a vacuum under the influence of sunlight, cellulose has little reducing power. This explains why direct dyestuffs do not fade in a vacuum under the influence of sunlight. (5) Most dyestuffs do not fade in the absence of fibre and air; direct dyestuffs do not fade in the absence of fibre; basic dyestuffs do not fade in absence of air. (6) Basic dyestuffs usually fade owing to oxidation. (7) Under the influence of mercury light, wool is not so powerful a reducing agent as cellulose. (8) Radium emanation has a powerful destroying action on cellulose, and on many direct and basic dyestuffs and on indigo; indanthrene and Para red, on the contrary, are only slightly affected. (9) Light from a mercury lamp browns and tenders both wool and silk. (10) Many substances affect the rate of fading of dyestuffs; oils, for example, assist the fading of vat dyestuffs through oxidation, whilst dextrin appears to protect all colors. To explain these observations the author advances a theory based on Drude's explanation of color absorption.

NOTES FROM THE CARNEGIE INSTITUTION OF WASHINGTON.

THE following publications have recently been issued:

No. 168. S. W. BURNHAM, "Measures of Proper-Motion Stars." Quarto, iv + 311 pages.

Micrometer measures made with the large telescope of the Yerkes Observatory from 1907 to 1912 of various stars having large, small, or uncertain proper-motions. These selected stars are of all magnitudes, from the faintest in Argelander to prominent naked-eye stars, and include, so far as possible, all those which have been heretofore compared by direct measures with other and fainter stars in the field. Independent differential values of the proper-motions are thus obtained for comparison with the results found from meridian observations. The latter values are frequently discordant and contradictory, and particularly so when the motions are small. The several values from the leading authorities on meridian-circle observations, Auwers, Newcomb, Porter, Boss, etc., and from the various standard star catalogues, are collected and compared. The greater number of proper-motion stars observed here are taken from the "General Catalogue of Double Stars." The others are selected from various sources and include stars of special interest, among others the Boss group of Taurus stars with a common movement in space, and small stars with supposed proper-motions taken from the Oxford and other astrographic catalogues. As a rule, each star is measured on three or more nights, and very faint comparison-stars selected which, it is safe to say, have no sensible motion which could affect the result obtained. No really faint star, not attached to and moving with a brighter star, has ever been shown to have any proper-motion which could be detected by any method of observation to this time. Of course, it is to be presumed that the faintest and most distant stars have both proper-motion and parallax, and it is equally obvious that the one is as negligible as the other in all differential comparisons. A careful remeasurement of these

small stars after a suitable interval of time will give the movement of the principal stars with a degree of accuracy not yet attained by other methods.

No. 180.—HARRY C. JONES and Collaborators, "The Freezing-point Lowering, Conductivity, and Viscosity of Solutions of Certain Electrolytes in Water, Methyl Alcohol, Ethyl Alcohol, Acetone, and Glycerol, and in Mixtures of these Solvents with one Another." Octavo, vii + 214 pages, 85 text figures.

The seven pieces of work incorporated in this monograph are a continuation of the investigations recorded in monograph No. 80, published in 1907. The effect of one hydrated salt on the hydration of another hydrated salt was worked out with a number of pairs of salts. The dissociation of a number of salts was determined by the freezing-point and conductivity methods. It was shown that the atoms or ions with the smallest volumes have the greatest hydrating power. The relation between hydrating power and electrical density is discussed. The dissociation in the alcohols was determined by the improved conductivity method.

Three investigations had to do with the physical chemistry of glycerol as a solvent. The conductivity and viscosity of solutions in glycerol as a solvent were studied at different temperatures, glycerol being a liquid solvent with enormous viscosity. The temperature coefficients of both conductivity and viscosity in glycerol were very great. The salts of ammonium and rubidium were found to lower the viscosity of glycerol. The explanation of this phenomenon, offered by Jones and Veazey in monograph No. 80, for aqueous solutions, was found to apply equally well for solutions in glycerol as the solvent.

No. 186.—CARL BARUS, "The Diffusion of Gases through Liquids, and Allied Experiments." Octavo, x + 88 pages, 38 text figures.

In 1900 the author began a series of experiments to determine the rate at which gases diffuse out of a submerged Cartesian diver through water. The method proved to be remarkably sensitive and the results striking. In the present volume the method is perfected, with a view to completing the measurements within a

reasonably short interval of time. Diffusions of air, hydrogen, and oxygen into each other, through water and a variety of solutions, are investigated in detail and the diffusion constants determined. It is shown that a method of exploring the internal channels or physical pores of liquids is probably in question. In the course of the work a number of other applications are included; for instance, the disk of an absolute electrometer is floated on a Cartesian diver submerged in hydrocarbon oil, and the potential is measured absolutely by the pressure needed to just suspend the diver in the liquid. All these results are given in full and in most cases charted, the curves being often of singular complication. It is shown why diffusion frequently occurs against the apparent pressure gradient.

No. 190.—HARRY C. JONES and J. S. GUY, "The Absorption Spectra of Solutions as Affected by Temperature and by Dilution: A Quantitative Study of Absorption Spectra by Means of the Radiomicrometer." Octavo, vii + 93 pages, 22 plates, 44 text figures.

A form of closed apparatus was devised and used for studying the absorption spectra of aqueous solutions up to 200°. It was found that the absorption bands widen with rise in temperature. The effect of dilution on the absorption spectra of solutions was also investigated over a range of dilution varying from 1 to 500. The absorption increased with the concentration, especially towards the red end of the spectrum. A radiomicrometer was built and used for study absorption spectra quantitatively. This permitted work at much greater wave-lengths than was possible by means of the grating spectroscope and photographic plate. The former was limited to $\lambda 7600$, while the latter can be used as far as $\lambda 30{,}000$, and even farther. The effect of dilution was also studied quantitatively by means of the radiomicrometer, and interesting and important results were obtained in reference to the effect of dilution on the nature and position of the transmission bands. It was found that "free" water had a different absorption from "combined," and this was regarded as further evidence for the solvate theory of solution. The absorption spectra of a fairly large number of salts were mapped by means of the radiomicrometer.

The following works are in the course of preparation and will appear shortly:

No. 88.—V. BJERKNES and Collaborators, "Dynamic Meteorology and Hydrography."

This work constitutes an advanced mathematico-physical treatise on the dynamics and thermodynamics of the atmosphere and the ocean, the main aim being to develop rational methods, based on the principles of dynamics and thermodynamics, for the investigations in meteorology and oceanography.

PART III, DYNAMICS.

No. 161.—F. R. MOULTON, in collaboration with DANIEL BUCHANAN, THOMAS BUCK, FRANK L. GRIFFIN, WILLIAM R. LONGLEY, and WILLIAM D. MACMILLAN, "Periodic Orbits."

A large part, though not all, of the periodic orbits treated in this book belong to the problem of three bodies. The first chapter contains certain theorems on implicit functions, the solutions of analytic differential equations, and a new treatment of linear homogeneous and non-homogeneous differential equations having periodic coefficients. The second contains a treatment of elliptic motion by the methods which have more general application. This is the simplest astronomical problem in periodic orbits. Certain additional methods are illustrated in the third chapter on the spherical pendulum, with new developments of certain elliptic functions. The fourth chapter treats of periodic motion about an oblate spheroid with applications to the motion of Jupiter's fifth satellite. The fifth chapter is devoted to a complete discussion of oscillating satellites in both two and three dimensions, in the case in which two of the bodies are finite and moving in circles, while the third is infinitesimal, and in which the centres of libration are collinear with the finite masses. Chapter VI is a treatment of the same problem by another method having important advantages in certain cases. Chapter VII is a discussion of the problem when the finite bodies move in elliptical orbits. Chapter VIII is a generalization of Lagrange's collinear solutions of the problem of three bodies to the general case of n bodies. Chapter IX is that of Chapter V for the equilateral triangular points of libration. Chapter X treats of the motion in the case

in which two masses are equal, the third infinitesimal or finite, and the three always occupying the vertices of an equilateral triangle. Chapter XI treats of satellites and inferior planets with application to the lunar theory. Chapter XII treats of superior planets. The problem of Chapter XIII is similar to that of Chapter XI, except that there are four or more bodies. Chapter XIV treats of the orbits of many small masses revolving around one large one. In all cases the existence of the periodic solutions is proved, methods of practically constructing them are given, and numerical illustrations are often added.

No. 165.—DERRICK N. LEHMER, "Tables Giving a Complete List of Prime Numbers Between the Limits 1 and 10006721."

Until the completion of the author's Factor Table for the first ten million numbers the construction of a reliable list of primes was impossible, owing to the numerous errors still undetected in the old tables of factors. The list of primes herewith published is taken from the corrected tables of factors and has been checked by comparison with the results of the count of primes made independently of factor tables by Meissel and Bertelsen. The number of primes in each successive thousand as counted by Glaisher has also been compared with the number obtained from the list. The results indicate a very high degree of accuracy for the list.

The successive primes are arranged in columns of one hundred, there being fifty columns to the page. Each page thus serves to list 5000 primes. The total number of pages is 133, and therefore the total number of primes listed is 665,000. The page is identical in size with the page of the Factor Table. The arrangement enables one to tell at a glance the rank of any particular prime and the number of primes between any two given limits.

No. 192.—ELLSWORTH HUNTINGTON, with contributions by CHARLES SCHUCHERT, A. E. DOUGLASS, and CHARLES J. KULLMER, "The Climatic Factor, as Illustrated in Arid America."

This study of changes of climate is a continuation of the work described in the author's papers in Nos. 26, published 1905, and 73, issued in 1908. It deals mainly with the relation of

climate to geological, botanical, and archæological phenomena, but contains also a considerable amount of geographical description. The book begins with a discussion of the present climate of Arizona and New Mexico, and its effect upon the earth's surface and upon vegetation. Because of the aridity and scanty vegetation, deposits of alluvium are abundant and many are terraced. A consideration of whether these terraces are of climatic or tectonic origin leads to the conclusion that they are climatic, and that they indicate climatic pulsations during the period of human occupation. Numerous ruins, here and in Mexico, Yucatan, and Guatemala, point to the same conclusion and suggest the existence of at least three moist periods separated by times of aridity.

An independent investigation of the same problem, based on the method of Prof. A. E. Douglass, shows that the amount of rainfall may be determined from the thickness of rings of growth in trees. From measurements of 450 Sequoias in California a curve has been plotted showing the approximate pulsations of rainfall in California for 3000 years. Comparison with meteorological records suggests that the pulsations consist of an alternate weakening and strengthening of atmospheric circulation, whereby climatic zones are moved first poleward, then equatorward.

This conclusion leads to an attempt to determine the cause of changes of climate, including not only recent changes, but those of geological times, which are discussed by Professor Schuchert, who lays special emphasis upon the importance of broad crustal deformation. Such deformation, however, can scarcely account for glacial and interglacial epochs, and much less for the pulsations indicated by the California trees. Only the solar hypothesis seems adequate. This conclusion is tested by investigating the possibility of a connection between variations in sun spots and changes in the growth of trees. Such a connection seems to exist, and various phenomena suggest that apparent discrepancies are in reality results that would naturally be expected.

Chapters 2, 4, 5, 6, and 10 deal with the geological problem of the effect of aridity upon surface forms and upon subaërial deposits. The problem of the tectonic *versus* climatic origin of alluvial terraces in dry mountain regions is treated at length. Chapters 19, 20, and 21 discuss theories of climatic changes, special emphasis being given to the solar hypothesis as the cause

of changes of the magnitude of glacial epochs or less, and to crustal deformation as the cause of greater changes, such as glacial periods.

Inasmuch as botanical evidence is largely used in elucidating the climate of the past, Chapter 2 describes the arboreal desert of the southwestern United States. Chapters 11 and 14 discuss the relation of the thickness of rings of growth to climatic conditions, not merely in the case of the Sequoia of California, but among trees from all parts of the country. The evidence presented in Chapters 15, 16, and 17 suggests that in equatorial regions plant formations may be displaced by climatic changes with a degree of rapidity which must cause the process of natural selection to act with greater speed than is commonly supposed.

The climate of the past stands in vital relation not only to geology and botany, but to men. Hence it is necessary to consider fully the ruins of the Southwest and the conditions under which the people lived. This is done in Chapters 6 to 10. The ruins and civilization of the Mayas in Yucatan and Guatemala are also important lines of evidence, and in Chapters 15 to 18 the theory is advanced that when the Mayas were in their prime the lowlands of this region were decidedly drier than now.

Petrol Substitutes. B. REDWOOD and V. B. LEWES. (*Times Eng. Suppl.*, July 23, 1913.)—Increased supplies of petrol are now obtained by compressing natural gas so as to condense pentane and hexane, a very light spirit being produced which is suitable for mixing with a heavier spirit to render the latter sufficiently volatile for use in carburettors. Oils of specific gravity 0.8, or a mixture of such oil with 40 to 60 per cent. of petrol, can now be used in special carburettors fitted with a supplementary feed tank containing petrol for starting. The heavier fractions of crude petroleum are converted into motor spirit by "cracking" in contact with iron, and an increase of 39 per cent. in the yield is obtained. The quantity of benzene available for motor spirit from gas works tar in England is only 50,000 gallons per annum, and it is doubtful whether motor spirit can be obtained profitably by distilling coal at low temperatures and "cracking" the naphtha distillates obtained from the tar. The maximum yield obtained at present is 3 gallons of motor spirit per ton of coal carbonized in coke ovens. The only motor spirit obtainable in unlimited quantities is alcohol, which could be made for the purpose and sold at 1 shilling (25 cents) per gallon.

The Heating Value of Gas. (*Times Eng.*, July 19, 1912.)—The committee of the House of Commons on unopposed bills has passed the bill authorizing the South Suburban Gas Company to acquire the undertakings of the Bromley and Crays and the West Kent Gas Companies. The most interesting feature of the bill is the adoption of a test for the calorific value of the gas supplied within the area of the amalgamated company, in substitution of the present penalty test for illuminating power. Penalties are attached for any deficiency in the prescribed standard of calorific value, but no penalty is incurred unless the gross calorific value falls below 475 B.T.U. per cubic foot. The substitution, which has been agreed to by the company on the suggestion of the London County Council, is due to the almost universal adoption of incandescent mantles and to the largely-increased use of gas for heating and cooking purposes.

Application of Low-Pressure Turbines. F. HODGKINSON. (*Elect. Journ.*, x, p. 317.)—Low-pressure turbines are more simple to design and construct on account of the lower temperatures and pressures involved, but much skill is required in their economical application. The three main problems which arise are: (1) Determination of the steam available; this is best made from the indicator cards. (2) What type of governing is to be used: whether the direct centrifugal or indirect electrical. (3) Is the introduction of a low-pressure turbine economically sound, or should the reciprocating engines be displaced by a complete turbine plant? Low-pressure turbine installations are divided into eight classes, each of which is discussed at considerable length. Each class is illustrated diagrammatically, and various practical considerations are brought into notice. The thermal efficiency of an exhaust steam turbine is only about ten per cent.

Radiation Pressure. G. D. WEST. (*Electr. World*, lxii, 5, 247.)—A paper read before the Physical Society. The pressure of the radiation emitted by a carbon-filament lamp at a distance of a few centimetres is sufficient to cause a microscopically measurable deflection of the end of a suspended strip of gold or aluminum foil, and by this means the radiation pressure can be calculated, if the weight of the strip is known. The results agree to within about 10 per cent. with the energy content per cubic centimetre as measured by the initial rate of rise of temperature of a copper plate exposed to the radiation. The best results are obtained by working in an atmosphere of hydrogen of 1 cm. to 2 cm. pressure, but good results are obtained with hydrogen at atmospheric pressure. Air at 1 cm. to 2 cm. pressure also gives good results. The method involves no laborious adjustments, and the apparatus is not seriously affected by vibration.

THE FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, Nov. 19, 1913.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 19, 1913.

PRESIDENT WALTON CLARK *in the Chair.*

Additions to membership, 31.

Dr. George A. Hoadley, on behalf of the Committee on Science and the Arts, introduced Mr. Halcolm Ellis, of Newark, N. J., who had been recommended by the Institute to the City of Philadelphia for the award of the John Scott Legacy Medal and Premium for his Adding Typewriter. The Chairman presented the medal to Mr. Ellis.

After the transaction of the above Institute business, a joint meeting was held with the American Society of Mechanical Engineers, President Clark and Chairman Yarnall, of the Philadelphia Section, presiding jointly.

Dr. R. H. Fernald, consulting engineer, U. S. Bureau of Mines, and Whitney Professor of Dynamical Engineering of the University of Pennsylvania, presented the paper of the evening on "Producer Gas from Low-grade Fuels."

The speaker described the results of investigations made by the U. S. Bureau of Mines on the utilization in gas producers of fuels heretofore not regarded as adapted to the economical production of power. Consideration was also given to important factors developed in these investigations, such as the practical elimination of the smoke nuisance, the centralization of power, development and the distribution of power.

The subject was illustrated by lantern slides and numerous specimens of various low-grade fuels.

In the discussion which followed the paper, Messrs. Henderson, Klumpp, Stratton, and others participated.

After a vote of thanks to the speaker the meeting adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, November 5, 1913.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, November 5, 1913.

MR. J. A. P. CRISFIELD *in the Chair.*

The following reports were presented for final action:

No. 2527.—Norton "Alundum." Edward Longstreth Medal of Merit. Adopted.

No. 2535.—Tirrill Voltage Regulator. John Scott Award recommended. Adopted.

No. 2543.—Kinkead Shaft Leveling Device. Edward Longstreth Medal of Merit. Adopted.

The following reports were presented for first reading:

No. 2536.—Coolidge's Malleable Tungsten. Investigation deferred.

No. 2537.—Cooper-Hewitt Mercury Rectifier.

No. 2538.—Pohle Air Lift. Advisory. Adopted.

The following applications were accepted for examination:

No. 2587.—Spielman's Cloth Cutting Machine.

No. 2588.—Rice's Gasoline Rock Drills.

The following subjects were recommended for examination:

No. 2589.—The Nitrogen-Filled Tungsten Lamp.

No. 2590.—Butterfield's Automatic Astronomical Calculator.

No. 2591.—Emmett's Electrical Propulsion of Ships.

R. B. OWENS,
Secretary.

SECTIONS.

Electrical Section.—A joint meeting of the Section and of the Philadelphia Section of the American Institute of Electrical Engineers was held in the Hall of The Franklin Institute on Thursday evening, October 23, 1913, at 8 o'clock.

Mr. H. A. Hornor and Mr. A. R. Cheyney presided jointly.

The minutes of the previous meeting were approved.

Mr. F. W. Peek, Jr., Consulting Engineer, General Electric Company, presented a paper entitled "High-Voltage Engineering," in which he considered some of the problems relating to the insulating of high-tension lines.

The subject was illustrated by lantern slides.

After some discussion, the thanks of the meeting were extended the speaker.

Adjourned.

WILLIAM E. BULLOCK,
Acting Secretary.

Mining and Metallurgical Section.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, October 30, 1913, at 8 o'clock.

Professor A. E. Outerbridge, Jr., occupied the chair.

The minutes of the previous meeting were approved.

Professor Bradley Stoughton, Consulting Metallurgical Engineer, New York City, presented a paper entitled "The Making of Sound Steel Ingots."

Professor Stoughton described the more important processes now employed for eliminating blowholes and impurities in casting ingots, thereby producing high quality material for structural and other purposes.

His paper was illustrated by lantern slides.

After some discussion, the thanks of the meeting were extended the speaker.

Adjourned.

WILLIAM E. BULLOCK,
Acting Secretary.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on the evening of November 6, 1913, at 8 o'clock, with Dr. Harry F. Keller in the chair.

The Chairman introduced Dr. Harry C. Jones, Professor of Physical Chemistry in the Johns Hopkins University, who delivered a lecture on "The Present State of Our Knowledge of Solution," in which he discussed the formation of hydrates and other solvates by dissolved electrolytes, as shown by the abnormal depression of the freezing-point, and by optical phenomena, such as absorption spectra and changes in the transparency of solutions. The lecture was illustrated by means of lantern slides.

The paper was discussed at great length; a vote of thanks was extended to Dr. Jones, and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

MEMBERSHIP NOTES.

Elections to Membership.

(*Stated Meeting of the Board of Managers, November 12, 1913.*)

RESIDENT.

MR. W. ASEF, 135-B South Forty-ninth Street, Philadelphia, Pa.

MR. FREDERICK WM. BARKER, JR., Benzol Products Company, Frankford, Philadelphia, Pa.

MR. EDMOND W. BUREAU, Southeast corner Twenty-third and Westmoreland Streets, Philadelphia, Pa.

MR. W. E. FIRTH, 400 West Chelten Avenue, Germantown, Philadelphia, Pa.

MR. CHARLES E. MACHOLD, 17 West Phil-Ellena Street, Germantown, Philadelphia, Pa.

MR. HAROLD MAITLAND, Sun Company, Marcus Hook, Pa.

DR. FRANCIS D. PATTERSON, Harrison Brothers and Company, Inc., 3500 Gray's Ferry Road, Philadelphia, Pa.

MR. THOMAS C. PINKERTON, The Chemical Laboratories, Inc., Northwest corner Thirteenth and Sansom Streets, Philadelphia, Pa.

MR. GEORGE RUECK, 37 North Sixty-third Street, Philadelphia, Pa.

MR. WM. STROBRIDGE, U. S. Cast Iron Pipe and Foundry Company, Burlington, N. J.

MR. WM. J. THORN, 1439 North Sixty-second Street, Philadelphia, Pa.

NON-RESIDENT.

MR. J. C. BANNISTER, National Tube Company, Kewanee, Ill.

MR. W. N. BEST, 11 Broadway, New York, N. Y.

MR. ABRAHAM G. BLAKELEY, P. & R. Coal and Iron Company, Pottsville, Pa.

MR. STERLING H. BUNNELL, The Griscom-Russell Company, 90 West Street, New York, N. Y.

MR. A. CHRISTIANSON, 198 West Pearl Street, Butler, Pa.
MR. F. H. CLARK, General Superintendent of Motive Power, B. & O. Railroad Company, Baltimore, Md.
MR. ALBERT E. CLUETT, P. O. Box 666, Troy, N. Y.
MR. F. J. COLE, 3 Avon Road, Schenectady, N. Y.
PROF. W. L. DUDLEY, Vanderbilt University, Nashville, Tenn.
MR. COLEMAN DU PONT, 27 Pine Street, New York, N. Y.
MR. A. H. EMERY, Glenbrook, Conn.
MR. C. N. FORREST, New York Testing Laboratory, Maurer, N. J.
MR. E. S. FRETZ, The Light Manufacturing and Foundry Company, Pottstown, Pa.
MR. EDWIN M. HERR, 140 Hutchinson Avenue, Swissvale, Pa.
MR. JULIUS A. KOCH, Pittsburgh College of Pharmacy, University of Pittsburgh, Pittsburgh, Pa.
MR. R. C. MCKINNEY, Niles-Bement-Pond Company, 111 Broadway, New York, N. Y.
MR. FRANK M. MASTERS, Modjeski & Angier, 101 Park Avenue, New York, N. Y.
MR. CHARLES S. VADNER, 2505 South Ninth East, Salt Lake City, Utah.
MR. HENRY H. VAUGHAN, 8 Weredale Park, Montreal, Canada.
MR. F. W. WESTON, 50 Church Street, New York, N. Y.

Changes of Address.

MR. WILLARD S. ATKINSON, Westmont, N. J.
MR. JOHN A. CAPP, 1332 Union Street, Schenectady, N. Y.
MR. ECKLEY B. COXE, JR., Drifton, Pa.
MR. J. H. EASTWICK, The Montevista, Sixty-third and Oxford Streets, Philadelphia, Pa.
MR. J. H. GRANBERY, 148 West Eleventh Street, New York, N. Y.
DR. HAROLD HIBBERT, P. O. Box 391, Wilmington, Del.
MR. B. B. MILNER, c/o Mr. H. L. Ingersoll, Assistant to Senior Vice-President New York Central Lines, Grand Central Terminal, New York, N. Y.
MR. WALTER PALMER, West Twenty-fourth Street, Chester, Pa.
MR. PERCIVAL ROBERTS, JR., 717 Commercial Trust Building, Philadelphia, Pa.

NECROLOGY.

Henry Pemberton, Jr., was born in Philadelphia, September 13, 1855. He was educated at the Western University of Pennsylvania, Pittsburgh, and entered the University of Pennsylvania, Philadelphia, as a special sudent in 1873, receiving a certificate of proficiency in June, 1875. He was chemist for the U. S. Chemical Company, Philadelphia, 1877 to 1883; manager of the Kalion Chemical Company, Philadelphia, 1883 to 1887, and of the Laramie (Wyo.) Chemical Works, 1888. He served as special agent of the eleventh census for the collection of statistics of the chemical industry. He was a member of the American Chemical Society and the Society of Chemical

Industry, and contributed numerous articles on technical subjects to the scientific journals. Mr. Pemberton became a member of the Institute on October 6, 1876, and was made a life member in October, 1890, he served on its Board of Managers from 1891 to 1896, and for many years was a member of the Committee on Library.

Arthur Lincoln Adams, Consulting Hydraulic Engineer, was born at Greensburg, Ind., in 1864, and died at Oakland, Cal., September 17, 1913. He was educated at Hanover, Ind., College, Washburn College, Kansas, and the Kansas State University. He served as engineer of the Burlington and Missouri River Railway, 1886 to 1887; Oregon and Pacific Railroad, 1887 to 1889, and for over ten years practised as a water works expert, having prepared plans for city water works at Dayton, Waitsburg and Colfax, Wash., La Grande and Astoria, Ore. Since 1902 he was in private consulting work. He was a member of the American Water Works Association, the Technical Society of the Pacific Coast, the New England Water Works Association; member and past director of the American Society of Civil Engineers, member and past president of the Pacific Association of Consulting Engineers. He became a non-resident member of the Institute May 11, 1900.

Sir William Henry Preece was born February 15, 1834, near Carnarvon, North Wales, and died in London, November 6, 1913. He was educated at King's College, London, and studied electricity at the Royal Institution under Michael Faraday. During the greater part of his life he was engaged in telegraph work. For many years he was an employee of the Electric Telegraph Company, which ceased its existence in 1870 when the control of the telegraph was taken over by the government. His connection with the Electric Telegraph Company began in 1852, when he entered the office of the late Edwin Clarke, its chief engineer. From 1854 to 1856 he was assistant to Latimer Clarke, and then became superintendent of the southern district. He became superintendent of the electrical system of the London and South-western Railroad in 1860, and in 1870 entered the Post Office Service as divisional engineer. He was appointed electrician in 1877, and engineer-in-chief and electrician in 1892. He retired from active service in 1899. Sir William visited the United States in 1877 and again in 1884. During the latter visit he was representative of the British Government at the Electrical Conference held under the auspices of The Franklin Institute at Philadelphia. Sir William began experimenting with wireless telegraphy in 1884, and worked out an electro-magnetic system, which was in practical operation between Larvernock, near Cardiff, and Flatholm, an island in the British Channel, a distance of more than three miles. Sir William was past president of the Institution of Electrical Engineers, and for several years president of the Institution of Civil Engineers; was a Fellow of the Royal Society, a member of the Physical Society, the Royal Institution, the Society of Arts, and the British Association for the Advancement of Science. His numerous inventions relate to the telephone, Wheatstone apparatus, the telegraph (duplex, quadruplex, multiplex, and wireless), and safety devices for rail-

ways. He was the author of works on telegraphy and telephony, and contributed many papers to scientific publications. He was knighted in 1899. Lt.-Col. George O. Squier, military *attaché* at the American Embassy, London, expressed to the family of Sir William Preece the sympathy of the members of the Institute and also represented the Institute at the memorial services held at St. Margaret's Church, Westminster, on Tuesday, November 11th.

J. G. Watmough, 2114 Walnut Street, Philadelphia, Pa.
Benjamin W. Carskaddon, Lansdowne, Pennsylvania.

LIBRARY NOTES.

Purchases.

ALEXANDER, WM.—Columns and Struts. 1912.
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COHN, G.—Die Pyrazolfarbstoffe. 1910.
COLVIN, F. H., and F. A. STANLEY.—American Machinist Grinding Book. 1912.
EIFFEL, G.—Resistance of the Air. 1913.
ERMEN, W. F. A.—Materials Used in Sizing. 1912.
FINLAY, G. I.—Introduction to the Study of Igneous Rocks. 1913.
GETMAN, F. H.—Outlines of Theoretical Chemistry. 1913.
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Electrical and Lighting Engineering, by Henry W. Spang. New York, 1913. (From the Author.)

Florida East Coast Railway Company, Annual Report 1913. New York, 1913. (From the Company.)

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Great Northern Railway Company, 24th Annual Report, 1913. No place, 1913. (From the Comptroller.)

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Wabash Railroad Company, 24th Annual Report, 1913. St. Louis, 1913. (From the Company.)

Washington University, University Studies, vol. 1, pt. 1, No. 1, July, 1913. St. Louis, 1913. (From the University.)

Western Australia Geological Survey: Bulletin 44, A Geological Reconnaissance of a Portion of the Southwest Division of Western Australia, by E. C. Saint-Smith. Perth, 1912. (From the Agent General for Western Australia.)

BOOK NOTICES.

AN INDUCTIVE CHEMISTRY, by Robert H. Bradbury, Ph.D., Head of the Department of Science, Southern High School, Philadelphia. D. Appleton & Co., New York and Chicago.

Among the great number of text-books which are now available for the teaching of chemistry in our secondary schools this is undoubtedly one of the best. While it may be questioned whether certain innovations the author makes in the arrangement and order of the topics, and in the development of the theory, will appeal to every teacher, we know of no other text that so thoroughly covers elementary chemistry, either as an end in itself or as a preparation for colleges and professional schools. Every paragraph gives evidence not only of the author's mastery of the subject, but also of his long teaching experience. Considering the size of the book, it is very remarkable what an amount of accurate and up-to-date information in all branches of chemistry—inorganic, physical, organic, and industrial—may be found between its covers; and all this matter is thoroughly assimilated in the clear and logical exposition. The book is printed in clear type on good paper; the illustrations by the author's wife are clear and very numerous. A series of fine portraits of the great chemists forms an attractive feature of the book.

HARRY F. KELLER.

REGULATION, VALUATION AND DEPRECIATION OF PUBLIC UTILITIES, by Samuel S. Wyer, Mech. and Cons. Engineer. Sears & Simpson Company, Columbus, Ohio, 1913. Thin paper, 314 pp., gilt edged, flexible leather binding. Price, $5, postpaid.

A compendium of technical, economic, and legal data relating to the regulation of public utilities, including a concise presentation of the principles on which the various regulations are based, and brief discussions of the practical application of these principles. The technical phases of the subject are illustrated by a series of graphical and pictorial representations, the economic data by numerous analytical diagrams, all very carefully prepared and unusually well executed. The legal questions are elucidated by brief citations of authoritative opinion, the various discussions being furthermore clarified by references to a long list of technical publications and citations of judicial opinions by the U. S. Supreme Court, the several U. S. Circuit Courts, the Interstate Commerce Commission, various State courts and public service commissions, and by the British Court of Chancery. A copious index completes the thoroughness of this altogether valuable compilation.

L. E. LEVY.

CHEMICAL GERMAN, by Francis C. Phillips. Easton, Pa., The Chemical Publishing Company, 1913. 241 pages (14 x 22 cm.). Price, $2.

Most courses in chemistry and chemical engineering require German for admission and include it in their curricula. Nevertheless, graduates of such courses are always unable to read German chemical journals intelligently.

This is merely another instance of the futile character of the instruction usually given in foreign languages. It is likely that hardly one-hundredth of one per cent. of the students who begin French or German ever get far enough to make any actual use of the language. Probably the chief reason for this state of things is that teachers, for some inexplicable reason, invariably lay the accent on learning to *speak* the language, instead of learning to *read* it. The ability to speak a foreign language is a mere showy accomplishment of very little practical value. Further, it is an accomplishment which, without residence in the country where the language is spoken, can be acquired only by a miracle. Finally, if the student should, in some extra-natural way, acquire a fluent speaking knowledge, he would begin to lose it at once through lack of practice, and in a few years the loss would be complete.

However that may be, the inability of young chemists to handle German is a serious matter, since the language is about as important to them as English. Professor Phillips thinks that he has discovered a contributing cause of the difficulty in imperfect specialization in the language teaching His book is an attempt to induct the student into the specific vocabulary of *chemical* science. There are about fifty pages of introductory exercises. The remainder of the book is occupied by selections from the literature of chemistry and by a vocabulary of chemical terms. The material offered is good, in the main, though naturally very unequal in merit. Some selections, like Victor Meyer's account of his discovery of thiophene, are of first-rate historical importance. On the other hand, the sciolistic characterizations of Berthollet and Scheele from Heller's "Geschichte der Physik" are of value only in so far as they show how completely the historian failed to grasp the significance of the work of these great chemists. There are hardly any technological selections.

All in all, the book is a good one. The student who masters it will be able to read the German journals without much difficulty. Without access to the German literature it is impossible for a chemist to inform himself thoroughly upon any topic.

ROBERT H. BRADBURY.

A NEW ERA IN CHEMISTRY. Some of the More Important Developments in General Chemistry during the Last Quarter of a Century. By Harry C. Jones, Professor of Physical Chemistry in Johns Hopkins University. New York: D. Van Nostrand Company, 1913. Pp. xii + 326. Price, $2.

In this book the author has traced very briefly the progress of theoretical chemistry during the past twenty-five years, indicating the chief points of difference between the older and the newer chemistry. Professor Jones's personal acquaintance with many of the pioneers of the "New Era" has enabled him to introduce interesting biographical sketches of these scientists and to enliven his book with some entertaining anecdotes.

After an introductory chapter on the condition of chemistry at the dawn of the "New Era" in 1887, the author proceeds to outline the development of the law of mass action, the hypotheses of Van't Hoff, Le Bel and Guye, the phase rule of Gibbs, the views of Van't Hoff and Le Chatelier on

chemical equilibrium, and the modern theory of solution, including the electrolytic dissociation theory of Arrhenius. In another chapter Professor Jones gives a concise summary of the series of investigations conducted in his own laboratory which have established the validity of the solvate theory of solutions.

The recent experimental work of Thomson, Rutherford and Mme. Curie is briefly described, and the bearing of this work upon chemical phenomena is discussed. The chapters devoted to the work of Ostwald and his pupils in the old Leipzig laboratory, in what is known as "Die gute Zeit," are most interesting.

An appendix containing short biographical sketches of Mendeléef, Kekulé, Gibbs, Ramsay, Van't Hoff, Ostwald, and Arrhenius must be ranked as one of the best chapters of the book.

It is to be regretted that the author chose the case of the precipitation of sodium chloride from a saturated solution by dry hydrochloric acid gas as an example of the change in solubility produced by adding to a salt solution an electrolyte with a common ion, since in this particular system complications have been shown to occur. Several typographical errors have been noted, but these are almost inevitable in a first edition and will undoubtedly be corrected in subsequent printings.

As an epitome of recent progress in one branch of chemical science this book should prove of interest to the general reader as well as to the scientific student, especially since it is written in the author's well-known enthusiastic style and escapes the dulness which so often characterizes books of this order.

FREDERICK H. GETMAN.

PUBLICATIONS RECEIVED.

Mellor, J. W. A Treatise on Quantitative Inorganic Analysis, with Special Reference to the Analysis of Clays, Silicates, and Related Minerals: being vol. i, of a treatise on ceramic industries, by J. W. Mellor, D. Sc. 778 pages, illustrations, plates, 8vo. London, Charles Griffin & Co., Ltd.; Philadelphia, J. B. Lippincott Company, 1913.

Abhandlungen aus dem Gebiete der Technischen Mechanik von Dr.-Ing. Otto Mohr, Geheimer Rat und Professor. Second edition, 567 pages, illustrations, 8vo. Berlin, Wilhelm Ernst and Son, 1914. Price, in paper, 18 marks.

Notions Fondamentales de Chimie Organique par Charles Moureu, membre de l'Institut et de l'Academie de Médicine. Fourth edition, revised, 383 pages, illustrations, 8vo. Paris, Gauthier-Villars, 1913. Price, in paper, 9 francs.

North Carolina Geological and Economic Survey: Economic Paper No. 33, Forest Fires in North Carolina during 1912 and National and Association Coöperative Fire Control, by J. S. Holmes, Forester. 63 pages, 8vo. Raleigh, State Printers, 1913.

Canada, Ministère des Mines, Division des Mines: Bulletin No. 4 (seconde édition), En quête sur les Tourbières et l'industrie de la tourbe a

Canada durant la paison 1909–10 par Aleph Anrep, Jr., expert en Tourbe. 48 pages, illustrations, plates, maps, 8vo. Minéraux industriels et industries minières du Canada par le Personnel de la Division de Mines, Marc Sauvelle, Traducteur. 85 pages, illustrations, plates, maps, 8vo. Rapport sur les dépôts de fer chromé des cantons de l'Est de la province de Quebec par Franz Cirkel, I. M. Traduit de l'Anglais par J. Obalski. 145 pages, illustrations, plates, maps, 8vo. Rapport sur les minerais de Tungstene du Canada par T. L. Walker, M.A., Ph.D. Traduit de l'Anglais par Jobson Paradis. 56 pages, illustrations, plates, 8vo. Ottawa, Imprimerie du Gobernement, 1913.

Konstant auftretende secundäre Maxima und Minima in dem jährlichen Verlauf der meteorologischen Erscheinungen, ix Teil von Dr. E. Van Rijckevorsel. Separatabzug aus Koninklijk Nederlandsch Meteorologisch Instituut No. 102. 33 pages, tables, 8vo. Utrecht, 1913.

U. S. Bureau of Mines: Miners' Circular 8, First-aid Instructions for Mines, by M. W. Glasgow, W. A. Raudenbush, and C. O. Roberts. 66 pages, illustrations, 8vo. Technical Paper 51, Petroleum Technology 11, Possible Causes of the Decline of Gas Wells and Suggested Methods of Prolonging Yield, by L. G. Huntley. 32 pages, illustrations, 8vo. Washington, Government Printing Office, 1913.

On Some New Multiple Relations of the Atomic Weights of Elementary Substances; and on the Classification and Transformations of Neon and Helium, by Henry Wilde, D.Sc., D.C.L., F.R.S. From volume 57, part iii, of "Memoirs and Proceedings of the Manchester Literary and Philosophical Society, Session 1912–1913," and from the *Philosophical Magazine* for October, 1913. 2 pamphlets, 8vo.

The Illumination of Street Railway Cars, by L. C. Porter and V. L. Staley. A paper read at a meeting of the Chicago Section of the Illuminating Engineering Society, November 12, 1913. 19 pages, illustrations, 8vo. New York, Society, 1913.

Temperature of Filaments in Incandescent Lamps. SUMMER. (*Electr. World,* lxii, 5, 245.)—A paper read before the German Illuminating Engineering Society on a new method of determining the true temperature of the filaments in incandescent lamps. If the law for the total radiation is known for a substance, and the radiation constant is also known in absolute units, it is possible to determine from the Joulean heat the true temperature of a filament of given surface, if the total electrical energy supplied to the filament is changed into radiation. For the absolute black body and for bright platinum the radiation laws are exactly known. For other metals the Aschkinass theory must be employed. The authors have experimented with platinum filaments and discuss the various assumptions made in this method.

CURRENT TOPICS.

Brush-Contact Resistance. ALFRED HAY, M. H. BRATT, and J. M. PARISH. (*Electr. World*, lxii, 5, 245.)—An illustrated account of experiments in brush-contact resistance, the main object of which was to ascertain how far the brush-contact drop is affected by the rotation of the commutator. In the method used care was taken to eliminate the effect of electromotive force in the armature due to imperfect commutation. The conclusion is reached that the brush-contact loss when a machine is running is, for all practical purposes, identical with that which occurs in a stationary armature, so that the loss can be easily determined by measurement with the armature at rest. This result agrees with that of several other experimenters, but differs radically from the results of Gratzmuller.

Application of Oxides Infrequently Used in Glass Manufacture. L. SPRINGER. (*Sprechsaal*, xlvi, 476, 495, 511, and 525.)—The introduction into glass of the oxides of barium, zinc, magnesium, aluminum, boron, and phosphorus is regarded from the points of view of history, raw material, properties, and application. *Barium oxide*, first used by Döbereiner at Jena in 1829, is used generally as carbonate, less often as sulphate or nitrate. It increases the specific gravity, refractive index, elasticity, and tenacity of glass, and imparts an attractive surface, but renders it more difficult to work, and also lessens the specific heat. Compared with calcium oxide, it is more expensive and does not impart chemical resistance, in this respect resembling more closely the alkali oxides. Barium glasses fuse more quickly than similar lime glasses. Barium finds its chief application in rolled glass, but is also used in hollow ware, crystal and table glass, and in special glasses, such as the Jena phosphate crown glass, which is essentially a barium metaphosphate containing 28 per cent. BaO and 60 per cent. P_2O_5. It can act as a substitute for lead oxide in crystal glasses, a suitable formula being: 4 Na_2O, 4 BaO, 4 CaO, 36 SiO_2. In table glass it can replace lime and soda. *Zinc oxide*, which was used in Belgian factories in the middle of the last century, is introduced as oxide under the names of zinc white, snow white, or crown white; also as zinc blende mixed with Glauber salt, and as calamine. The power of refraction it imparts is less than that produced by lime and much less than by lead and barium. It acts as a basic oxide like magnesia in producing a very low coefficient of expansion, for which reason it is used with boric acid in the manufacture of flashed glass. Zinc glasses have high tensile strength and high resistance, physical and chemical; they tend to crystalliza-

tion and devitrification. They are used chiefly for laboratory and optical purposes. *Magnesium oxide* is introduced as the carbonate, usually with lime in dolomite, but many feldspars, granites, basalts, etc., contain as much as 10 per cent. MgO. Calcspars, with a magnesia content of 18 per cent., have been used. It has thus found application in glass from the earliest times without contemporary recognition in the literature of the subject. It finds its greatest employment in the French factories. Magnesia increases the fluidity and lowers the viscosity of molten glass and influences fusibility favorably, also the tendency to devitrification and the chemical resistance; the most suitable amount is 2 to 10 per cent. *Aluminum oxide* renders glass difficultly fusible, but prevents devitrification. It is introduced as clay, bauxite, or feldspar, but the range of raw materials was extended at the end of the last century to include lavas and other similar aluminum silicates. The presence of alumina enables the lime content to be increased without making the glass rough. It makes glass chemically resistant. Alumina is used chiefly in the manufacture of flasks, acid receptacles, etc., the content being 4 to 10 per cent. *Boric acid,* which is found to be a constituent of old Venetian glass, is introduced as the crystalline hydrate or as borax. It imparts high refractiveness, and in the spectrum reduces the proportion of blue to red, a relation which had previously been exaggerated in flint and crown glass. The coefficient of expansion, the tendency to devitrification, and the melting-point are lowered by high boric acid content. When boric acid is used in conjunction with other acid oxides, the glasses, as for example borosilicate glass, are very resistant to chemical action if the proportion of boric acid be not greater than 10 per cent. Boric acid is employed in crystal and optical glass. *Phosphoric acid* is introduced as bone ash or other phosphate. It is used for optical purposes, often in conjunction with boric acid. Phosphor-crown glass may contain as much as 70 per cent. P_2O_5. *Arsenic* and *antimony* are used in glass making to assist the progress of chemical reactions and as decolorizers. Jena cylinder glass has a high boric acid content with 4 per cent. Sb_2O_3.

Formation of Hydrochloric Acid in the Distillation of Petroleum. E. PYHÄLÄ. (*Petroleum,* viii, 1603.)—The corrosion of the iron retorts used in distilling crude petroleum is found to be due to the presence of free hydrochloric acid in the aqueous portion of the distillate. The quantity of the acid was 0.107, 0.043, and 0.026 per cent. in samples of oil containing 29, 12, and 7 per cent. of water respectively. Water, separated from the crude oil and having a specific gravity of 1.1426 at 20° C., yielded 0.33 per cent. of hydrochloric acid when distilled. The acid was not formed until 86 per cent. of the water was distilled over, the temperature then being 125° to 130° C. The acid is probably formed by the decomposition of the chlorides held in solution in the water.

Tantalum as a Cathode Material. G. OESTERHELD. (*Z. Elektrochem.*, xix, 585.)—Tantalum electrodes have a potential difference against sulphuric acid about midway between those of copper and lead. They possess the disadvantage, for many electrolytic purposes, of readily absorbing cathodic hydrogen, which produces a considerable change of structure even when less than 0.1 per cent. is absorbed. The hardness and elasticity of the metal disappear, and it becomes useless as an electrode material. The paper contains measurements relative to the velocity of absorption of hydrogen and to its influence on the overvoltage.

Formation of Methane. L. VIGNON. (*Comptes Rendus*, clvii, 131.)—Methane is formed from water vapor and carbon monoxide when they are heated together to temperatures ranging from 500° C. to 1200° C. in the presence of catalysts—iron, nickel, copper, silica, alumina, magnesia—in greater or less degree, sometimes in considerable quantity. In some cases there is an intermediate formation of carbides, which react with the steam; in others hydrogen is produced, which in presence of the catalyst reacts with the carbon monoxide.

Melting-Points of Refractory Metals. ANON. (*Brass World*, ix, 10, 349.)—These are recent determinations made by G. K. Burgess and R. G. Waltenberg, and the results are given in the *Journal of the Washington Academy of Science*. They are:

	C.°	F.°
Titanium	1795	3263
Vanadium	1720	3128
Chromium	1520	2768
Manganese	1260	2300
Iron	1530	2786
Cobalt	1478	2692
Nickel	1452	2545

The determinations were made with a micro-pyrometer, and the metals were melted in hydrogen gas to prevent oxidation. In some cases the metals were melted in an Arsem electric vacuum furnace.

A Refractory Furnace Lining. ANON. (*Brass World*, ix, 10, 360.)—For certain purposes, a furnace lining of a refractory nature may be made from asbestos and water-glass. It is useful for patching or plugging cracks, as it does not crumble as readily as other similar compositions made from clay. The materials used are:

Fine asbestos	40 pounds
Water-glass	60 pounds

The water-glass is the sodium silicate of commerce, which is soluble in water. The asbestos and water-glass are mixed to a paste with water so that it can be worked.

Searchlight. GOERGES. (*Electr. World*, lxii, 5, 245.)—A paper read before the Dresden Electrical Society. It describes tests of a searchlamp with a mirror of 600 mm. diameter and 260 mm. focus, the arc lamp being operated normally at 80 ampères and provided with horizontal carbons. The searchlight was tested in an inside room at 85 volts and 80 ampères, 100 ampères, and 120 ampères, with carbons of different manufacture and of different diameters. With highest concentration of the light the maximum illumination obtained was 850,000 lux. There seems no reason why searchlamps of the largest size cannot be tested in inside rooms of sufficient dimensions. Tests of searchlamps in the free air over long distances will always yield uncertain results, because the transparency of the air varies greatly.

Substitute for Platinum. ANON. (*Electr. World*, lxii, 5, 217.)—Among the problems encountered by makers of large-size incandescent lamps or rectifying apparatus, not the least important is that of obtaining an air-tight joint between the leading-in wires and the lamp or rectifier bulb. With small units satisfactory results are secured by the use of platinum, of which the coefficient of thermal expansion is the same as that of the glass bulb. In addition to the high cost of platinum, there are several reasons why this method is not equally satisfactory when applied to large units. On page 246 a brief description is given of a recent development in accordance with which tubular leading-in conductors of platinum, copper, or other high-conductivity metal are employed instead of solid wires of platinum. The secret of the process lies in avoiding any appreciable local differences of temperature while making the seal. If the method proves as satisfactory in practice as one is led to believe from the description, it will find wide application in the production of large lamps and rectifiers, with some possibility of causing the substitution of copper for platinum in small incandescent lamps. First the electrical conductor is inserted through an aperture in the glass. The glass around the conductor is then strongly heated by means of a blowpipe flame until perfect cohesion has been attained between the glass and the conductor. The seal is now removed from the flame, and when it reaches a dull red heat the leading-in wire and the glass surrounding it are cooled by several immersions in a special bath. The bath may be sperm or other oil, wax or fat, and should be previously warmed slightly. Each immersion should last two or three seconds. The depth of immersion is increased with each successive dip until the seal is completely cooled. If the conductor is required to carry a current of not more than 15 ampères it may be a solid wire, if of more than 15 ampères the conductor should be tubular, filled with an electrical conducting substance. With German and lead glasses, copper, nickel, platinum, etc., may be used, but with Jena glass and fused quartz it is necessary to use platinum.

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